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6

B. Walker.

John Monaghan's
Property

PAD

John Monahan

LECTURES

ON

NATURAL AND EXPERIMENTAL PHILOSOPHY,

CONSIDERED IN IT'S PRESENT STATE OF

IMPROVEMENT.

DESCRIBING, IN A FAMILIAR AND EASY MANNER,

THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING,

THAT THEY ALL CO-OPERATE IN DISPLAYING

THE

GOODNESS, WISDOM, AND POWER OF GOD.

BY GEORGE ADAMS,

Mathematical Inſtrument Maker to His Majeſty, and Optician to His Royal Highneſs the Prince of Wales.

VOL. III.

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LECTURES
ON
NATURAL PHILOSOPHY.

OF THE
NATURE AND PROPERTIES OF
MATTER.

LECTURE XXIV.

LET us for a moment compare this univerſe to a palace, erected by a DIVINE ARCHITECT; and the unphiloſophical ſpectator to a foreigner, who only ſees the external part of the building. From ſo ſuperficial a view, it is evident he can obtain but a very unſatisfactory idea of the ſkill and contrivance of the GREAT DESIGNER. To form a more accurate conception, to perceive it's beauties, to diſcover it's conveniences, it is neceſſary to enter the building, to view each apartment ſeparately, to compare the convenience of every room ſingly, with the ſymmetry and elegance of the whole.

In the ſame manner the beauties of nature ſtrike our view: we find curioſity allured by a variety of objects, animals, vegetables, minerals, air, water, and fire: all put on different appearances to pleaſe, aſſiſt, or aſtoniſh us: but in order to come at a knowledge of their nature, we muſt ap-

The inveſtigation of *properties* in the ſenſe here uſed, conſiſts in examining the *phenomena* belonging to the ſubſtance in queſtion; and aſcending from one *effect* to another, till you arrive at ſomething which is a *cauſe* agreeable to the foregoing definition; that is, which evidently and clearly ariſes from the idea of the ſubſtance conſidered, and which cannot be ſeparated from it without annihilating the ſubſtance, or being inſeparable therefrom by any human conception.

It has been uſual to reckon among the *properties* of MATTER, *impenetrability, extenſion, figure, diviſibility, hardneſs, inertia, motion, attraction, and repulſion.* I know of no other which have a right to be examined, as affecting the ſenſes, which, as I have often obſerved, can alone conſtitute the ſcience of phyſics. Let us then compare the ideas of theſe properties with the preceding definition, and you will ſoon ſee that the three laſt mentioned muſt be excluded from the claſs of *properties* ſo defined, and cannot with ſtrict propriety be termed the characters of materiality.

Impenetrability, conſidered as expreſſing that two particles of what conſtitutes *matter* (whatever it may be) cannot exiſt at the ſame time in the ſame place, ſo long as one retains it's place it muſt neceſſarily exclude the other, is undoubtedly a phyſical axiom; the contrary propoſition would be a contradiction.

The phyſical world would vaniſh from the eyes of the underſtanding, and we ſhould no longer have any notion thereof, if impenetrability, as here conſidered, was not an *eſſential property of matter.* There could be no exiſtence of this *ſubſtance*, unleſs the idea of *impenetrability* immediately aroſe from it. As it is neither the exiſtence of the ſubſtance, nor the cauſe of it's exiſtence, that we are conſidering,

ing, but it's *properties*, there can be no doubt of this firſt principle.

For as ſoon as *matter* exiſts, it is impenetrable; this is the firſt thing which conſtitutes it's exiſtence as matter, that is, as a part of the phyſical world, an object of the five ſenſes.

Every thing therefore, which is deduced from the *impenetrability of matter*, will be the reſult of what I have called a primary cauſe, and is ſubordinate to nothing elſe but the cauſe of the exiſtence of *matter*.

Extenſion is another property of the ſame kind; it is indeed included in the idea of *impenetrability*, when it is conſidered with reſpect to ſpace, namely, that two particles of matter cannot exiſt at the ſame time in the ſame place; they are therefore *extended*, that is, they occupy a certain portion of ſpace. Extenſion is therefore an eſſentially conſtituent property of matter.

Figure is another property that neceſſarily flows from the preceding definition, or rather from the exiſtence of matter itſelf. Whatever is material, muſt have *figure* or ſhape; every finite extenſion is terminated or comprehended under ſome *figure*.

So far there cannot be two modes of thinking concerning the properties of matter, unleſs ſome other ſpecies of being is meant by the word *matter*, in which caſe it would not belong to our phyſical world, that which affects our ſenſes. But the remaining *properties* require a cloſer examination.

Diviſibility. If this expreſſion be confined to the poſſibility of conceiving that every *atom* of *matter* may be indefinitely divided by a ſufficient power; that is to ſay, that when conſidered as *extended*, a right and a left may be always ſeparated by the mind, and by a ſufficient power could be continually ſeparated, it neceſſarily flows from the idea of matter as here defined.

Hardneſs. This property muſt be entered into more fully, as at firſt ſight it ſeems contrary to the diviſibility of matter; but here you are to conſider that the diviſibility of matter does not include the idea of an *actual* diviſion. The *atoms* or firſt elements of matter, that is, the ſmalleſt actual diviſions, had an undivided (an indiviſible) extenſion at ſome period of the phyſical world.

I do not here ſpeak of the origin of matter; but the exiſtence thereof being once admitted, it muſt neceſſarily poſſeſs indiviſible particles. *An actual infinite diviſion* is an expreſſion without any ſenſe or meaning, it is contrary to the very *exiſtence* of *matter*; if then, in order to avoid abſurdity, it be neceſſary that the idea of matter ſhould contain that of indiviſible particles, we muſt admit that there is a minimum, below which, though bodies may be capable of being reduced, there is no power in the phyſical world by which they can be divided or reduced. That is, no ſhock or impact that takes place in the phyſical univerſe can break or ſubdivide theſe elements; and this is what I here mean by *hardneſs*, a quality eaſily underſtood, and which implies no other cauſe than the exiſtence of matter. I therefore admit it without repugnance as an hypothetical property, which is rendered ſtill more probable as it connects itſelf with the phenomena.

Thus then I have pointed out to you three properties which are eſſential to matter as above defined, and without which you can form no idea thereof. 1. Impenetrability, whereby it excludes other matter from the ſpace it occupies. 2. Whatever is material muſt have ſize and extenſion, and yet the largeſt ultimate particle of matter is in all probability incomparably ſmaller than any point philoſophers can form a diſtinct idea of, or than they can have any real occaſion to ſuppoſe ſubſervient to human reſearches in nature. 3. Whatever is material muſt have *figure* or ſhape; if this were not a property of every the ſmalleſt unit of matter, no collection of them could acquire it by combination or coheſion. 4. *Diviſibility*, when conſidered not as an aſſertion of the *actual* poſſibility of dividing any parcel of matter without end, but as the poſſibility of conceiving extenſion as continually diviſible into leſſer and leſſer extenſions: an unit of nature *is not compoſed of mathematical points* cohering together by attraction, or any power a name can be invented for; a mathematical point is a nothing, (a non-entity,) and an infinite number of ſuch can never form one atom of matter. 5. *Hardneſs*, or the indiviſibility of atoms or firſt elements of matter: one atom may be divided from another, but no atom can be divided from itſelf. Theſe properties are ſo eſſential to matter, that they may be termed the *characters of materiality*, as they are each of them inſeparable from any poſſible conception human creatures can attain of the particles of the material or phyſical univerſe.

Before I proceed to examine the other properties that I heretofore mentioned to you, it will be proper to guard you againſt the miſtakes that ſome have fallen into in treating of the properties already explained. Thus, Mr. Locke, to ſhew that ſolidity was a property of water, uſing the word ſolidity as ſynonymous to impenetrability, mentions the Florentine experiment; but he has certainly applied this experiment to an improper purpoſe, and ſo far from clearing the idea he meant to explain, it renders it more confuſed and perplexed.

The experiment is as follows: a hollow globe of gold was filled with water and exactly cloſed; the globe thus filled being preſſed with the extreme force of ſcrews, the water made itſelf way through the pores of that cloſe and compact metal, and appeared upon the ſurface in little drops like thoſe of dew, before the ſides of the globe could be made to yield to the violent compreſſion of the ſcrews that ſqueezed it. This experiment may be uſed to ſhew the poroſity of gold, or the great force neceſſary to compreſs water, but by no means to demonſtrate the impenetrability of water. Muſt we have granted that water was not impenetrable or ſolid, if the globe had yielded while all the water was in it? And yet if the globe had been filled with air, it might have been preſſed inward, though none of the air had eſcaped; and that not becauſe the particles of air are not impenetrable, but becauſe it is a more compreſſible fluid, ſo that the particles may be ſqueezed cloſer together, and the ſame quantity thus be made to occupy a ſmaller ſpace.

An optical illuſion has been introduced by ſome to prove, that there may be extenſion without ſolidity. By an image formed at a certain diſtance, between a concave mirror and any one looking into it, *extenſion and form* become an object of ſenſe, where there is no *ſenſible reſiſtance*; but this does not prove that an image is formed in *empty ſpace*, or where there is no matter; for as the ſenſes can be affected only by matter, they infallibly determine where it is, ſo that we are as certain matter exiſts where we ſee any thing, though we cannot feel it, as we ſhould be certain there was matter where we felt it, though we could not ſee it.

It is here neceſſary to ſay ſomething concerning *ſpace*, of which ſome ideas have been entertained very contrary to ſound *phyſics*. The only poſitive idea that can be applied to *ſpace* is *extenſion; but no idea ſhould be applied to any ſubject, which the ſubject itſelf does not impreſs.*

Matter forces upon our ſenſes the idea or image of it's dimenſions or extenſion: but it is a kind of philoſophical felony to ſteal an image which nature gives us, and inveſt a ſubject with it that *never* excited any idea in us, and conſequently has *no exiſtence* to us; we thus create *nothing* into a being, by applying ideas to it which we derive from *ſomething.*

Space is only one of thoſe ideas that are excited in the mind by matter, and the power in the mind of abſtracting from it's ſubject, juſt as we can image a colour to ourſelves, without connecting in our apprehenſion a ſubject with it wherein it exiſts; a little more of the ſame metaphyſics which can prove that nothing is extended, will prove that ſpace is purple. It is a very ingenious contrivance in philoſophers to render *nothing* a ſubject of inquiry and conception, by dreſſing it in a ſuit of clothes borrowed from *ſomething,* and then gravely tell us that this nothing is the form of God.*

In the ſame manner, much falſe reaſoning has been introduced in treating of the *infinite diviſibility* of matter; and the truth of this hypotheſis is ſaid to reſt on mathematical demonſtration. The arguments drawn from the mathematics in favour of this queſtion, demonſtrate the poſſible infinite diviſibility of *that body,* which is the object of ſuch inveſtigation; but there is an eſſential diſtinction between *body mathematical* and *body phyſical.*

From not attending to this diſtinction, many philoſophers are no limits between matter and nothing. To aſſert, that there cannot be ſuch a thing as an unit of matter, is to maintain, that matter has an infinite property. To ſay, that any portion of matter is finite, and at the ſame time that it's component parts are infinite, is philoſophy baffling with itſelf, and maintaining contradictions.

---

* See Dr. Wilſon's "Obſervations on Principles and moving Powers aſſumed by the preſent Syſtem."

Time is made up of a perpetual ſucceſſion of years and days, and is meaſured by hours, and minutes, and ſeconds: now, there would be juſt as much truth in aſſerting, that a *moment* of time, by ſubdiviſion, may be lengthened out into a *thouſand ages*, as there is in ſaying, that a *grain* of ſand may be rarified and enlarged into the *bulk of a planet*. Nothing can be more ſhocking to reaſon than *eternal time*; infinite diviſibility is not leſs abſurd.

Concretes, in which form matter is made ſubject to the ſenſes, can no more be without atoms, or firſt principles, than numbers in arithmetic can be without units.

Having ſhewn you the abſurdity of ſuppoſing matter to be infinitely diviſible, I ſhall now endeavour to give you ſome idea of the parts actually *ſeparate*, and give you inſtances where you will find the parts ſo ſmall and ſo numerous, as almoſt to ſurpaſs imagination.

Though plants, by their exhalations, loſe ſo great a quantity of their ſubſtance, yet we cannot affirm, that the part aſſigned for propagating their ſmell, ſuffers much by this ſenſible decay. It appears, that the fragrant parts are endued with ſuch prodigious diviſibility, that they can furniſh ſufficient for the purpoſe, and with very little loſs for a long courſe of time. Every body knows, that a grain of muſk will make itſelf ſmell in a manner not very agreeable, for a ſpace of twenty years, in an apartment where freſh air is admitted every day.

A grain of leaf gold will cover 50 ſquare inches, and contains two millions of viſible parts. But the gold which covers the ſilver wire, uſed in making gold lace, is ſpread over a ſurface twelve times as great. In making this wire, it is uſual to gild ſtrongly a cylindrical bar of ſilver, and afterwards to draw it into wire, by drawing it ſucceſſively through holes of different magnitudes, formed in plates of ſteel. By this means, the ſurface is prodigiouſly augmented; notwithſtanding which it remains gilt, ſo as to preſerve an uniform appearance, even when examined with the microſcope. It has been calculated, that a ſingle grain of gold would cover a ſurface thirty yards ſquare.

FURTHER CONSIDERATIONS ON ATOMS.

Atoms muſt originally ſubſiſt in numbers, which cannot be increaſed or diminiſhed; it is equally impoſſible for many to become one, as it is for an unit to be multiplied: ſo that the original number of atoms is as invariable as their ſizes. An atom may as ſoon be reduced to nothing, as two can be made to coaleſce into an unchangeable ſubſtance.

Number is the fundamental baſis of motion and changes in matter. An atom cannot act upon itſelf, nor communicate action, impreſſed intimately to it's ſubſtance, though ever ſo large; but a concrete can and does impreſs it's own inward parts, in a mechanical proportion to the power which acts upon it's ſurface. If any body, though ever ſo ſmall, has numerical parts, their coheſion muſt be mechanical; and nature can do nothing, but what, under certain circumſtances, it can undo again. To this purpoſe *Sir Iſaac Newton*

If *attraction* be a principle, or primary property of matter, how is it that it can be weakened, ſuſpended for a time, and even quite deſtroyed? If it be a power determining matter to matter, as a real eſſential property, how comes it to be overpowered and deſtroyed by matter, acting mechanically upon matter, ſince ſuch action muſt always be conſiſtent with, and ſubſervient to, it's original properties? Now, the force of fire will ſuſpend the ſtrongeſt attractions. From all we can underſtand of the units of which matter is compoſed, a maſs of them lying together, unacted upon by a mechanical material agency, would neither attract, gravitate, nor take place of one another.

Matter hath *a capacity of motion*, not an ability to move; neither doth any matter act but ſo far as it is acted upon. The trumpet hath a capacity of ſounding, but never till it is ſounded; of itſelf it is dead and ſilent, and would, if left to itſelf, remain ſo for ever. To inveſt matter with any innate powers, call them by what names (attraction, &c.) you pleaſe, is as contrary to the real nature of matter, as to ſuppoſe that all trumpets are born with lips and lungs, and breath of their own. A ſtringed inſtrument has the capacity of ſending forth all poſſible harmony; but it muſt firſt be acted upon either by the vibratory motion of the air, or immediately by the hand of the maſter. Such then is the mobility of matter; it is a capacity of being moved and acted upon, but no motive faculty of any kind with itſelf.

The operations in nature, as far as we can trace them, are carried on mechanically; and though our ſenſes are limited as to the *minutiæ* of that mechaniſm, yet we are certain that matter does exiſt in ſuch forms, as will aſſure us the mechaniſm may go on further than we can deſcribe. All the properties of matter fit it to act and be acted upon in a natural way.

Though matter is not infinitely diviſible, yet it is certain it's primordial atoms are indefinitely ſmall, ſo as to be far beyond the reach of our ſenſes. At the ſame time our organs are machines, ſo exquiſitely conſtructed, as to be ſubject to the impreſſions of the ſmalleſt.

But though the units of matter are ſo ſmall as to elude our ſenſes, it does not therefore follow, that we can have no certain knowledge of them or of their properties. From the knowledge of concretes, we may clearly diſcover what are the general and invariable properties of their conſtituent atoms. Every concrete enjoy's two kinds of properties: *the firſt* are ſuch as are inſeparable from it as matter, and theſe properties belong to every atom of which a concrete is compoſed; *the ſecond* are ſuch as are produced from matter variouſly combined in concretes; the latter are not the original properties, though naturally produced by them. You are therefore to be cautious, leſt you ſhould aſcribe the different properties which matter acquires in a concrete form, unto the original atoms themſelves: thus, for inſtance, you might as juſtly conclude, that the units of which ivory are compoſed, are white, as that they are elaſtic.

OF INERTIA AND GRAVITY.

As I am now going to conſider properties that relate to motion, it will be neceſſary to proceed with care and circumſpection. " That matter at reſt will perſevere for ever in that ſtate, unleſs it be compelled by ſome cauſe to move," is one of the ideas philoſophers have included in the word *inertia*; and as far as this idea goes, without

out

out conſidering it as a primary property of matter, on account of it's relation to motion, it may be conſidered as true.

To the other idea, which is often included in that of *inertia*, there are many objections, and I think you will heſitate long ere you adopt it. By this we are taught, "that any particle of matter, which has been once put in motion, will move on for ever with the ſame velocity, unleſs ſtopped or reſiſted." I do not know that any thing can be ſtarted more unphiloſophical than this notion; a notion which gives to matter an eternal power of changing it's place, in conſequence of it's being once diſquieted. But leaving every other conſideration out of the place, as we do not know what motion is in itſelf, it would be a queſtion, whether the *inertia*, here ſuppoſed, flowed from the nature of matter or motion; a queſtion that may be ranked among thoſe that are indeterminable. This alone will exclude *inertia* in the ſecond ſenſe of the word, from the number of properties.

In the Lectures on Mechanics it is ſhewn, that the notion of the *vis inertiæ*, in the ſecond ſenſe, is repugnant to ſound reaſoning, and unſupported by any experimental evidence, and to leſſen the effect of prejudice, it is there alſo ſhewn, that ſome of the firſt mathematicians have confeſſed, that the *vis inertiæ*, conſidered in the ſenſe uſually attributed thereto, muſt be abandoned.

The *reſiſtance* obſerved in matter, ariſes from that certain determination, which all the parts of matter are under, from their ſituation and connection in the general ſyſtem; and in conſequence of which, they require a force to turn them out of that way, which is appointed to them by the eſtabliſhed laws of nature. How far any parcel of matter would reſiſt, if it could be taken independent of the preſent frame of nature, and what force would be requiſite in ſuch a caſe, to move any given quantity of matter in all directions indifferently, we cannot tell, becauſe we cannot place any matter in ſuch a ſtate to make a trial.

I muſt own it appears to me exceeding clear, "*that no particle of matter can move a ſingle inſtant, without the preſence of the moving cauſe.*" In this propoſition, *motion* is indeed conſidered, not as a mere *modification*, but as ſomething *real*, and which is always foreign to *matter*; ſo much ſo, that matter continually obeys an active cauſe, which flows originally from a claſs of *beings* totally diſtinct from that *ſubſtance*, which has *impenetrability*, *extent*, *figure*, *diviſibility*, *hardneſs*, and *inertia* in the firſt ſenſe, for it's characteriſtic properties: a claſs of beings, which are not the object of any of our five ſenſes, *except by this property of motion*, which is perceived by us when it is communicated to *matter*; but of which we can form no conception, while we have only our *five ſenſes*, or, in other words, while we are deſtitute of a *ſenſe* analogous to the cauſe of motion.

Neither can I perceive any objection to this notion, as it is only the extenſion of another, that I admit in the fulleſt and moſt abſolute manner, namely, that the firſt cauſe of *motion* neither is nor can be in *matter*; conſequently *motion* cannot be admitted as a property of matter.

Nor do I conceive how any one could poſſibly conceive that *motion* was eſſential to matter! How can any thing which has *degrees*, which may be divided by communication, be conſidered as an *eſſential property?* If ſo, all reaſoning on theſe ſubjects is at an end. That, and that only, can be termed an *eſſential property*, which is inſeparable, even by the imagination, from the ſubject to which it is attributed. Every thing elſe is only *phenomenon*.

I ſee that matter, in a general ſenſe, follows the laws of motion; but then theſe laws belong only to a *communicated* modification, for they alſo may be communicated, which is contrary to all notions of an eſſential or primary property. I feel as intuitively as I do any other axiom, that *matter* is *eſſentially impenetrable, extended, figured, diviſible,* and that the *atoms* thereof *may be hard,* that every particle at reſt perſeveres therein till ſomething puts it in motion. But I perceive alſo, with the ſame degree of evidence, that the idea of *motion* may be ſeparated from that of *matter*, as eaſily as that of any other evident modification. If I muſt then allow that motion is *eſſential* to matter, in order to have the nature of man and the univerſe explained to me, I would rather chooſe to be ignorant. And I exhort you to avoid ſuch inſtructors; *knowledge* you cannot obtain from them. Let *Dinarzade*, in the Arabian Tales, amuſe herſelf with fictions: but do you ſeek for truth.

Let us proceed, and by conſidering one of the known *laws* of the *motions* which prevail in the univerſe, we ſhall perceive what further ſuppoſitions are neceſſary to the propoſition we are combating. The law to be conſidered is that of *gravity*, by which NEWTON has ſpread ſo much light over the phyſical ſyſtem of the univerſe. Now among philoſophers there are thoſe to be found, who conſider gravity *as an eſſential property of matter*. We will endeavour to diſcover what can be meant by ſuch a ſtrange aſſertion.

Gravity is that *general phenomenon*, or that *law*, in the operations of nature, whereby bodies approach each other; and which acts as far as obſervations have hitherto determined, *in the direct ratio of the maſſes, but inverſely as the ſquares of the diſtances*. By it matter is grouped into maſſes of different kinds; by it, and a ſimple rectilinear *motion*,

motion, which is perpetuated, the celeſtial orbs revolve in their orbits. This is the *law* that ſome would have us conſider as *an eſſential property of matter.*

But who can conceive that a body *can act where it is not*; act without any thing intermediate? To ſuppoſe that two diſtant bodies ſhould, without the aſſiſtance of any intermediate ſubſtance, produce motion in each other, is to inveſt matter with a power of beginning motion itſelf; a poſition falſe and dangerous, and which has been turned to the purpoſes of atheiſm, by a modern philoſopher of France. What two particles of *matter* are at 100,000 leagues, or at the 100,000,000th part of an inch from each other, without any *material* communication between them; and yet, on *account* of the one the other is *moved!!* Again, without any thing happening to one of the particles, let the other be placed at half the diſtance at which it was before, and they will move towards each other *four times* quicker! What magic power *determines them?* What! only becauſe the diſtance is leſſened, which is a mere *non-entity*, when there is no intermediate *agent*, the tendency increaſes, and that accurately in a certain *ratio!* Let us ſhut our books of *ſpeculative philoſophy*, if they all hold this language; for it is worſe than unintelligible.

It is not eaſy to comprehend how thoſe philoſophers, who reject a *ſpiritual* principle, an *immaterial ſoul* in man, " becauſe they cannot conceive that a reciprocal action can take place between two ſubſtances which are not of the ſame nature," can, neverthleſs, digeſt, and allow a reciprocal action between the particles of the *moon* and thoſe of the *earth*, without any thing *intermediate*, but the magical power of the words, GRAVITY *is an eſſential property of matter.*

If each particle of matter was even poſſeſſed of intelligence, and could determine itſelf by motives, ſtill it would be neceſſary to *inform* them of the ſurrounding bodies, to *acquaint* them with their maſs, their relative poſitions and diſtances; in a word, of every thing that cauſes a particle to *move* towards a certain point, with a certain velocity.—Who are the *aides de camp* that give this information? For ſuch there muſt neceſſarily be.

Till there has been a ſerious and ſound anſwer given to this queſtion, conſider *gravity*, and in general whatever elſe is included under the notions of *attraction* and *repulſion*, only as *appearances* or *phenomena*.

It was thus they were conſidered by that great man who has inſtructed us. NEWTON never conſidered *gravity* or it's *laws* but as facts. He aſſerts clearly, that he only uſed the words *attraction* and *repulſion*, to expreſs effects of *cauſes* more remote, which general *effects* explained particular ſubordinate effects. And he declared at the ſame time, that he conceived theſe general effects might be produced by impulſion, and tried to explain them as well as the particular *attractions and repulſions*, perceived in certain phenomena, by means of an univerſal elaſtic fluid, that he called ether, aſcending always to a cauſe foreign to *matter*, for a firſt ſource of *motion*.

Remember, that though it may be difficult to find a *mechanical cauſe* of *gravity*, which ſhall be altogether ſatisfactory, it is not difficult, as you have ſeen, to ſhew the abſolute neceſſity for ſuch a cauſe.

So long as you keep within the limits of *phyſics*, you muſt account for the motions of nature, by referring them to *mechanical* cauſes; and where this cannot be done, you muſt conſider them only as *appearances*, till you ſhall have ſome further light by experience. Be not amuſed with *names* and *qualities*, which contradict the known laws of mechaniſm, and are uſed to ſuperſede the *agency of the elements*.

OF ATTRACTION AND REPULSION.

The univerſe appears to be one great machine, fitted and diſpoſed to perform all the operations which are carried on throughout the whole. No one part of it ſhould be conſidered as acting, without being acted upon; and no individual can be conſidered as an agent, without being a patient. It is unphiloſophical to ſay, matter in general, or any portion, has eſſential or ſeparate properties, by which one part *acts upon another*. It is the eſſential property of no one wheel in a machine to move it's fellow, though, in conſequence of it's being placed in the ſtation it is fitted for, it acts upon it's fellow, becauſe it is acted upon.

It is exactly the ſame with the whole ſyſtem of nature. You cannot take up any parcel of matter, and ſay thereof, This has eſſential, ſeparate properties, which empower it to be a natural *agent*. A philoſopher ſhould conſider it as a concrete, with a certain diſpoſition of it's parts, liable to be acted upon by the more ſubtil parts of the machine. And it may as juſtly be aſſerted, that it is the eſſential property of animal ſubſtances to live, as that it is the eſſential property of the loadſtone to attract.

The viſible ſyſtem of this world, created, diſpoſed, and ſet in motion by the POWER OF GOD, acts as a machine does, a connection and communication being preſerved between all the diſtant parts. And you will find a mechanical agency takes place, to produce all the phenomena that ſurround you, and is concerned in the formation, growth, and ſupport of animals and vegetables: the more you conſider and obſerve the whole ſyſtem of nature, the more clearly you will perceive, that *impulſe* is the only known *material* cauſe of motion.

There are appearances, which have been haſtily conſidered as *ſources* of motion, without any adequate cauſe; theſe are generally known by the names of *attraction* and *repulſion*, and are diſtinguiſhed into ſeveral kinds; that of bodies falling to the earth, is called the *attraction of gravity*, or ſimply *gravity*; that of the ſmall parts of bodies to each other, is called the *attraction of coheſion*, and ſo of other ſpecies.

Here I muſt again caution you not to let words ſupply the place of real agents, or cauſes, where *no cauſes* have been *diſcovered*. Names may be uſed, as expreſſive of *appearances*, or to diſtinguiſh one appearance from another, but no further; thus the motion of ſmall bodies approaching each other, as that of iron to the magnet, or that of bodies falling to the earth, may with propriety be diſtinguiſhed from each other, by peculiar names, as magnetic attraction, attraction of gravity, &c. &c. But if you uſe theſe words for another purpoſe, and ſay, *attraction* is the *cauſe* of coheſion, the uſe is perverted, and becomes very exceptionable; they are then no longer the names of things perceived, *of facts*, but they become names of *imaginary* and *unknown* things.

Thus, when it is ſaid, that the parts of bodies cohere by attraction, what idea have you of the thing ſignified by the word attraction? If you ſay, bodies deſcend to the earth by their gravity, what idea have you of this gravity? If you ſay, they gravitate by attraction, what do you mean by the word attraction different from the fact?

We are under a neceſſity of giving a *name* to every *known* fact, whether cauſe or effect; but we ought not to give a name to a cauſe, while it is *unknown;* for this would be to uſe words without ideas, to perplex the mind, and to retard the progreſs of knowledge, by ſubſtituting an appearance for a reality.

If you examine the writers on this part of philoſophy, you will find their notions vague, crude, and contradictory; ſometimes the word attraction has no fixed meaning; ſometimes it is cauſe, ſometimes effect; you will find their anſwers to every queſtion concerning it unſatisfactory. If you aſk, where attraction is ſeated, for inſtance, whether it be in the earth, or in the ſtone that falls down to it, or in both, or in neither, but in ſome ſubſtance exterior to both, you can obtain no anſwer. If you inquire, whether it be a material or an immaterial force, you are ſtill left in the dark.

Many and greater are the difficulties and objections behind againſt the uſe of this word; but for a full account of theſe, and of the contradictory manner in which it has been uſed by various writers, I muſt refer you to the Rev. Mr. William Jones's "Eſſay on the Firſt Principles of Natural Philoſophy," and ſhall only give you ſome inſtances where it has been applied improperly to explain phenomena.

Aqua fortis will diſſolve iron. If you aſk why? the anſwer is ready, becauſe the particles of iron are more attracted by thoſe of aqua fortis, than either the particles of iron are by each other, or the particles of aqua fortis by each other. By this attraction, the particles of iron and aqua fortis are ſeparated from each other, and by the ſame attraction they are mixed and blended together.

But then, this aqua fortis will not diſſolve gold; but why? The anſwer is ready, for *words* are eaſily put together. There is no attraction between gold and aqua fortis. If you aſk, why aqua fortis, which will not diſſolve gold, will diſſolve ſilver? the anſwer is ready, and the ſame as before; aqua fortis either does not attract gold at all, or elſe the mutual attraction of the particles of gold amongſt one another, is greater than the force with which they are attracted by the aqua fortis. Aſk again, why aqua regia, which will diſſolve gold, does not diſſolve ſilver? you are again anſwered, that aqua regia attracts gold, but does not attract ſilver.

To evince how unſatisfactory a method this is, of accounting for diſſolution, you need only aſk thoſe who maintain it, what they mean by the word *attraction?* Put the word *drawing* inſtead of it, and you will find what they ſay may amuſe but not inſtruct. Thus inquire why aqua fortis diſſolves iron, or draws the particles of a maſs of iron aſunder. You are anſwered, becauſe aqua fortis attracts them more than they are attracted by each other, which is juſt the ſame as to ſay, that aqua fortis draws them aſunder with a greater force than they draw one another. Now, *this is only to aſſign the fact* (phenomenon) *as a reaſon for itſelf;* it is ſaying, aqua fortis will draw iron aſunder, becauſe it has a ſufficient force to draw it aſunder. This account is therefore very unſatisfactory; for I wanted not to be informed that aqua fortis has ſuch a force, for that my ſenſes informed me; I wanted not a name for a fact; I wanted to know what the force is by which the effect is produced.

It might be inquired what atraction this is which diſſolves hard bodies in fluids? Is it the attraction of coheſion? If they ſay no, but quite a different ſpecies; I do not ſee how they get rid of the charge of introducing ſo many different attractions into nature, and thereby rendering their explanations no better than the *Ariſtotelian* one, by *occult qualities*, *inſcrutable principles*, *indeterminate powers.* If they ſay, by the attraction of coheſion; they are evidently miſtaken, for the bodies do not cohere ſo ſtrongly as before. And it may be here obſerved, to the credit of *Ariſtotle*, and his numerous followers, that though they ſupplied their ignorance by terms of art, yet they never aſſumed any previous maxim, which, while received, entirely prevented diſcovering the falſity and abſurdity of their occult qualities.

Lord Bacon conſidered all nature "as *filled* with an *aërial* or *fiery* nature," and denied that the pores or cavities of tangible bodies admit of a vacuum, but that they contain either *air* or a ſubtil *ſpirit* proper to their nature and diſpoſition. He treats this ſpirit as a *material* cauſe, rejecting all ſolutions as *pretended*, *unmeaning*, and *unphiloſophical*, which are deduced from *virtues* and *qualities* in matter, with which the ſchools in his times did very much abound. " Whatſoever is inviſible," ſays he, " either in reſpect of the fineneſs of the body itſelf, or the ſmallneſs of the parts, is but little inquired; and yet theſe be the things that GOVERN NATURE principally, and without which you cannot make a true *analyſis* and indication of her *proceedings.* The ſpirits or *pneumaticals* that are *in* all tangible bodies, are ſcarce known; ſometimes they take them for a *vacuum*, whereas they are the moſt active of bodies; ſometimes they take them for air, from which they differ as much as wine from water; ſometimes they will have them to be natural heat, whereas ſome of them are cold; and ſometimes they will have them to be the *virtues* and *qualities* of tangible parts which they ſee, whereas they are things by themſelves; and when they come to plants and living creatures, they call them ſouls; and ſuch ſuperficial ſpeculations they have; like proſpectives that ſhew things inward, when they are but paintings. Neither *is this a queſtion of words*, but infinitely material in nature. As to the motions corporal within the incloſures of bodies, whereby the *effects* paſs between the *ſpirits* and the *tangible parts*, which are rarifaction, colliquation, concoction, maturation, &c. they are not at all handled, but they are put off by the *names* of *virtues* and *nature*, &c. and ſuch other words."

This reaſoning will be illuſtrated by conſidering another inſtance, where the word *attraction* and it's magic powers have been ſubſtituted in the room of the true agents to explain effects; thus leading men to conceive falſely of nature, and to affirm what is contrary to experience.*

Immerge a glaſs tube into water, or any other fluid except mercury, the fluid will be raiſed to a certain height within the tube above the ſurface of the fluid in the veſſel, and it's elevation in ſeveral tubes of different ſizes will be reciprocally as the diameters of their bores.

The fluid is ſaid to be drawn up by a tendency it has from the principle of attraction, till the ſurface is loaded with as great a weight as that tendency can ſupport; from hence we are told, that *a right notion is obtained of the aſcent of ſap in vegetables.*

If the ſap aſcends in vegetables on the ſame principles that water riſes in a capillary tube, in thoſe of the ſame diameter, the ſap ſhould be raiſed to the ſame height, but no higher. Now, take one, for inſtance, in which water will be raiſed *two inches*: in a tube of a plant a heavy viſcous juice will iſſue plentifully at the height of two feet, and that from veſſels conſiderably larger than the orifice of a capillary tube.

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* Jones's Eſſay on the Firſt Principles of Natural Philoſophy, p. 172.

The ſame quantity of liquor will be *ſuſpended* in a capillary tube, when it's lower orifice is lifted out of the water, as was raiſed in it while immerſed under the ſurface. If the ſap aſcended in a vegetable on the ſame principle, it ought to remain there, and be ſuſtained by the attractive power of the veſſels, when the orifices of them are expoſed to the air. The contrary appears from experiment. If a branch of *the birch* be taken off, or a young tree be cut away, and held in the ſame perpendicular poſture in which it grew, the veſſels will bleed copiouſly from the bottom, as when a limb is cut off from an animal; and the like will happen to many other plants. Again, water will never run out at the upper orifice of a capillary tube, be it ever ſo ſhort; but the ſtump of a vine will ſend up it's ſap into a tube cemented upon it to the height of 20 feet and upwards: the juices *are not* therefore *attracted* by the plant, but forcibly compelled into it's veſſels.

In a capillary tube it makes no difference whether there is air on the ſurface of the water or no, for the experiment will ſucceed equally well in *vacuo*: but it is not ſo with the vegetable; no plant will take up it's nouriſhment, no ſeed will germinate, as long as the air is abſent.

The capillary tube will not raiſe water to a greater height at one part of the year than at another; but the rays of the ſun, or the heat of an artificial fire, are ſo neceſſary to the growth of herbs, that in their ſeaſon for taking ſap, in their ſtature, and in their other qualities, they are wholly influenced by the ſun's heat. When the ſun is at it's greateſt exaltation in ſummer, the whole vegetable creation is in it's greateſt glory and

Sink a piece of metal in the center of the veſſel, ſo that the top thereof may be above the ſurface of the water; the cork placed at a proper diſtance will approach the piece of metal.

Raiſe the water until the metal is covered, and the cork will remain at reſt at any diſtance from the metal.

In all theſe experiments, except the third, the water which ſurrounds the balls is elevated, as is alſo the water by the ſide of the containing veſſel.

Pieces of dry cork, or painted balls, placed gently on water and near together, will approach each other; but if one be placed near the ſide of the containing veſſel, adjoining to which the water is elevated, it will recede.

That theſe phenomena do not depend on attraction, is clear, 1. Becauſe in the third experiment they recede from the ſide to which they adhered in the firſt. 2. Becauſe the balls, around which the fluid is depreſſed, univerſally recede from thoſe around which it is elevated. 3. Becauſe they are not attracted by bodies exceedingly near, when thoſe bodies are perfectly covered with water. 4. Becauſe aſſigning attraction as a *cauſe* is contrary to all ſound reaſoning in phyſics.

It is no doubt better with Mr. *Banks*, *s'Graveſande*, &c. to explain theſe phenomena on *hydroſtatical* principles. Every body that ſwims impreſſes the fluid with a force equal to it's own weight; the fluid re-acts, and preſſes the ſupported body with the ſame force; the ſides of the body are alſo preſſed by the ſurrounding fluid with forces which are as the depth. If the encompaſſing water be elevated round the body, the preſſure will ſtill be the ſame, or equal on oppoſite ſides, ſo that without force the body cannot move; but if it be placed ſo near the ſide, that it's elevated water joins, the water elevated at the ſide of the veſſel or by another ball, the preſſure on that ſide is diminiſhed, while that on the other ſide, remaining the ſame, will cauſe it to approach the ſide or other ball.

In the ſame manner, if the fluid be depreſſed when the cavities meet, the preſſure on that ſide will be diminiſhed, and the bodies of conſequence approach each other on the ſide of the veſſel.*

The receſs in the third experiment ariſes from the preſſure being ſuperior on that ſide next the glaſs, when the fluid is elevated above it, and the elevation round the ball joins the declining ſurface near the edge; for when the elevated fluid ſurrounding the ball, is cauſed to join the declining ſurface of the ſupporting fluid, it muſt then gravitate and preſs in all directions with more force, as there is more of it elevated above the ſurface of the ſupporting water.†

In theſe caſes‡ the attraction and repulſion is accounted for by the action of *intervening fluids.* Perhaps the elaſticity of the air, electricity, and all other elaſtic fluids, may be explained in the ſame manner, that is, by ſuppoſing the mixture of a ſyſtem of fluids, ſome of which are capable of permeating glaſs and other ſolids, as light, fire, magnetiſm, &c. ſo that when air, for inſtance, is condenſed in a veſſel, the finer fluids are forced through the ſides, and ſuffer the particles of air to approach nearer together.

Or,

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* When the circles of ſurrounding water meet, the preſſure on the exterior ſides forces them to form one circle, as two bubbles or drops of water unite and form one larger, and thus brings the corks, &c. together.

† If one cork raiſes, and the other depreſſes the water, the water, in endeavouring to reſtore the level, comes between and puſhes them aſunder.

‡ Bennet, Mancheſter Tranſactions, vol. iii. p. 123.

gether, as in the caſe of this extraordinary column.

When the tube is open at both ends, and the atmoſphere has acceſs to each, the air then acts againſt itſelf, and the mercury falls by it's gravity into the ciſtern.

When the upper end is cloſed, the air then acts at one end and not at the other; and this is the reaſon why the mercury is ſuſtained in the tube till it is a counterpoiſe to the atmoſphere.

On the ſame principle you may account for the higher or longer column. When the more ſubtil medium which can penetrate the mercury has poſſeſſion of the top of the cavity in the upper part of the tube, it acts at each end; and being thus a counter-ballance to itſelf, nothing remains but the preſſure of the air, which ſupports a column equal in weight to itſelf.

But when that medium is excluded at top by the perfect contact between the mercury and the glaſs, and cannot paſs readily through the ſubſtance of the glaſs, it acts only on the open end in conjunction with the air, and thus produces a much greater effect of the ſame kind than the air can do when it acts by itſelf.

Thus the extraordinary column is found to act on the ſame principle with the ordinary column, the one being from the preſſure of the air only, the other from the preſſure of air and fire together; as they are ſuſtained on the ſame principle, ſo do they alſo fall or ſubſide on the ſame principle. If air inſinuates itſelf at the lower and open end of the tube, it aſcends to the top, and by it's elaſticity and expanſion depreſſes the mercury; if more enters, it is more depreſſed; if a continual ſtream of air is admitted, it keeps aſcending to the top till it has expelled the mercury.

Now this is what actually happens in the other caſe, for when once the more ſubtil element is admitted to the top by reaſon of the ſmalleſt ſeparation of the mercury from the glaſs, it follows rapidly in a ſtream till it has got full poſſeſſion, and reduced the column to a counterpoiſe with common air. To prevent this, it is neceſſary that the contact muſt be rendered as abſolute as poſſible by thoroughly purging the mercury from it's air.

This experiment puts us in poſſeſſion of a principle, which in it's application will be found almoſt as extenſive as philoſophy itſelf. The preſſure of the atmoſphere, as demonſtrated and explained by the torricellian tube, enables you to give a ſatisfactory account of many phenomena, about which words had been multiplied for ages to little purpoſe. Here we have another force which comes in to our aid, and will carry us through higher and more ſubtil phenomena, where air is inadequate; coheſion with ſuch a medium as this is no longer difficult; and as to gravity,* if a column of ſo great a weight does not fall becauſe the medium is not admitted to fetch it down, I can ſee no difference between that and the cauſe of gravity.

OF GRAVITY CONSIDERED AS A FACT.

Gravity is that force by which all bodies, when left to themſelves, fall towards the ſurface of the earth.

The ſame force which cauſes them to fall when they are not ſupported, cauſes them to preſs on

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* See the ſentiments of Mr. Huygens, Dr. Wallis, and Dr. Jurin, Phil. Tranſ. abridged by Lowthorp, vol. ii. p. 25, &c. vol. v. p. 191.

on thoſe obſtacles which retain and prevent them from falling; thus a ſtone weighs or preſſes on the hand which ſupports it, and falls in a line perpendicular to the horizon as ſoon as the hand lets it go.

It was always known that bodies left to themſelves deſcended towards the earth, and preſſed the hand which prevented them from falling; but as there were ſome bodies whoſe weight was ſcarce ſenſible, and which roſe in the air, as feathers, ſmoke, flame, exhalations, &c. Ariſtotle ſaid that there were two kinds of appetence (*appetentia*) poſſeſſed by different bodies, one by which they tended to the center of the earth, which he ſuppoſed to be the center of the univerſe, the other by which certain bodies were driven from this center.

Ariſtotle taught alſo, that all bodies fell in different mediums with velocities proportional to their maſſes; but Galileo ſhewed, that the reſiſtance of the mediums was the only cauſe of any difference in the deſcent of bodies, and that *in an unreſiſting medium all bodies would deſcend with the ſame velocity* In the air indeed a piece of lead will fall faſter than a feather, but this is owing to the reſiſtance they meet with from the air; for in an exhauſted receiver, you have ſeen, that if they are both let fall from the top at the ſame inſtant, they will both come to the bottom together, and having fallen from the ſame height in the ſame time, they muſt have moved with equal velocities; conſequently the forces whereby bodies deſcend, muſt, at equal diſtances from the earth, be as the quantities of ponderable particles in the deſcending bodies. For if a certain force be neceſſary to carry down a certain quantity of matter with a certain ſwiftneſs, then double the force will be required to carry down double the quantity of gravitating matter with the ſame velocity, and a triple force to carry down a triple quantity of matter; ſo that the weights of different bodies at equal diſtances from the center of the earth, or the forces with which they deſcend freely, or endeavour to deſcend, are to each other as their quantities of *ponderable* matter.

That the gravity of bodies is proportional to their quantities of gravitating matter, and does not depend upon the figure or the texture of their parts, is evident from experiments on the motion of pendulums: for when the lengths of the pendulums are equal, bodies of very different bulks, and different internal and external texture, perform their vibrations in times exactly equal in equal arcs, keeping always pace together, and acquiring always equal velocities at the correſponding points of thoſe arcs, unleſs ſo far as the reſiſtance of the air may act upon them unequally.

Now the quantity of motion in each is the product of it's weight by it's velocity; and as the velocity is the ſame, it will be in proportion to the quantity of gravitating matter in each. But the force producing motion is in proportion to the quantity of motion produced; conſequently gravity, which is the producing force, acts in proportion to the quantities of gravitating matter.

The force of gravity above the ſurface of the earth, decreaſes in the ſame proportion that the ſquares of the diſtances from the center increaſes; ſo that if a body, at the ſurface of the earth, (which is 4000 miles diſtant from the center,) weighs 4 pounds, and falls through 16 feet in a ſecond of time, it will at double that diſtance weigh but one pound, and will fall through but 4 feet in a ſecond of time.

The force of gravity, when conſidered as acting differently on bodies at different diſtances from the center, is called the *accelerating* force, and is meaſured by the velocity it is able to generate in a given time.

Though gravity, ſtrictly ſpeaking, decreaſes in the manner above-mentioned, yet, where the diſtances from the earth's ſurface are inconſiderable compared with the earth's radius, the force of gravity may be conſidered as equal at all ſuch diſtances. Thus, for inſtance, the gravity of a body at the diſtance of half a mile from the earth, may be conſidered as equal to the gravity thereof at the diſtance of a quarter of a mile, or at the ſurface itſelf; for the difference is ſo ſmall, that if it be rejected, it will not occaſion any error in the calculations.

Gravity does not vary; *it acts equally on all bodies at all times,* whether they be in motion or at reſt, and thus uniformly accelerates the motion of a falling body; that is, the velocity thereof will be increaſed, and the increments will be equal in equal times.

A few conſiderations will ſhew you, that a force conſtantly and equally acting, will produce an uniform acceleration of velocity; for if you ſuppoſe the time of deſcent to be divided into a number of equal parts indefinitely ſmall, in each of theſe, gravity muſt make equal impreſſions on the body to carry it downwards, and muſt conſequently by each impulſe generate a velocity in the falling body equal to the former. Now as all the velocities are in the ſame direction, the laſt acquired muſt be ſtill added to the former; that is, the velocity given in the firſt portion of time, will be doubled in the ſecond, tripled in the third, quadrupled in the fourth, and ſo on continually through the ſeveral portions of time; and therefore the velocity of the body will be uniformly accelerated.

To be a little more particular, let us ſuppoſe a body begins to move with a velocity conſtant and gradually increaſing, in ſuch a manner as would carry it through a mile in a minute; at the end of this ſpace, it will have acquired a velocity ſufficient to carry it through two miles the next minute, though it ſhould then receive no new impulſe from the cauſe by which it was accelerated: but if the ſame accelerating cauſe continues, it will carry the body a mile farther; on which account it will have run through four miles at the end of two minutes; and then it will have acquired ſuch velocity, as is ſufficient to carry it through a double ſpace in as much more time, or eight miles in two minutes, even though the accelerating force ſhould act upon it no more.

But this force ſtill continuing to operate in an uniform manner, will again, in an equal time, produce an equal effect; and ſo by carrying it a mile further, cauſe it to move through five miles in the third minute, for the velocity already acquired, and the velocity ſtill acquiring, will each have it's complete effect.

From hence we learn, that if the body ſhould move one mile the firſt minute, it will move three miles the ſecond minute, five the third, ſeven the fourth, nine the fifth, and ſo on in proportion.

So that the ſpaces deſcribed by an uniformly accelerated motion, are always as the odd numbers 1, 3, 5, 7, &c. and conſequently the whole ſpaces are as the ſquares of the times, or of the laſt acquired velocities: for the continued addition of the odd numbers yields the ſquares of all numbers from unity upwards. Thus 1 is the firſt odd number, and 1 is the ſquare of one; 3, the next number added to 1, makes 4, which is the ſquare of 2; five added to four makes 9, the ſquare of three, and ſo on for ever. Now the *times* and *velocities* proceed evenly and conſtantly, as 1, 2, 3, 4, &c. but the *ſpaces* deſcribed in each, as 1, 3, 5, 7, &c.; it therefore follows, that the ſpaces deſcribed

In 1 minute will be - - -	1 equal ſquare of	1
In 2 minutes - - -	1 + 3 - - -	2
In 3 minutes - -	1 + 3 + 5 - - -	3
In 4 minutes -	1 + 3 + 5 + 7 - - -	4

Wherefore the ſpaces deſcribed in different times by a falling body, are to each other *as the ſquares of the times from the beginning of the fall*, or as the ſquares of the velocities acquired at the end of thoſe times.

As the motion of a body falling from a ſtate of reſt is uniformly accelerated, ſo likewiſe the motion of a body thrown directly upwards is uniformly retarded; for the ſame force of gravity, which conſpires with the motion of a falling body, acts in direct oppoſition to the motion of ſuch as aſcend; therefore it will retard the one in the ſame manner that it accelerated the other.

Whence it follows, that a body thrown directly upwards, will continue to aſcend for a time, equal to that in which, by falling from a ſtate of reſt, it would acquire the ſame velocity with which it was thrown up. For ſince the action of gravity is conſtant and uniform, in whatever time it generates any velocity in a falling body, in the very ſame time it muſt deſtroy that velocity in a riſing body.

Hence, if a body be thrown directly upwards with a velocity equal to that which it acquired by falling from any height, it will aſcend to the ſame height before it loſes all it's velocity.

To determine the abſolute force of gravity at the ſurface of the earth, it is neceſſary to know through what ſpace a body will fall in a given time; and by very accurate experiments on the pendulum, it is found, that a body near the ſurface of the earth, falling from a ſtate of reſt, will deſcend through the ſpace of about 193 inches in a ſecond of time; conſequently the force of gravity acting on a body only for one ſecond of time, will give it ſuch a velocity, as being continued uniform, would carry it through 32 feet 2 inches in one ſecond, or through very near 22 miles in an hour.

Here, however, I muſt obſerve to you, that bodies do not deſcend in all climates at the rate of 193 inches in a ſecond of time, but only in ſuch places as are in or near the latitude of 49 degrees. In places *more* diſtant from the equator, the deſcent is *quicker*, and ſlower in thoſe *nearer* thereto. For it has appeared, from a great number of obſervations, that the force of gravity is leſs under the equator, and that it continually increaſes as you approach towards the poles, where it is greateſt.

This difference ariſes chiefly from the rotation of the earth round it's axis, by which all bodies on the ſurface acquire a centrifugal * force, and would fly off if they were not retained by their gravity.

Now, as all theſe bodies revolve uniformly round the earth's axis in 24 hours, either in the equator, or in circles parallel to it, their velocities, and conſequently their centrifugal forces, muſt be as the peripheries of the circles they deſcribe; and therefore, as the equator is the greateſt of all thoſe circles, and the others grow leſs and leſs as they are more and more diſtant from the equator, the centrifugal force of bodies muſt be greateſt in the equator, and be continually diminiſhed towards the poles, till at laſt it vaniſhes at the polar points. As this force acts in oppoſition to gravity, it muſt of courſe diminiſh it, and this diminution muſt be greateſt in the equator, and grow leſs and leſs in the approach towards the poles.

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* By the centrifugal force is meant, that force which we ſee makes bodies lying looſely on a wheel, or a globe, fly off when it revolves ſwiftly round it's axle; and this ariſes from their tendency to move on in a right line.

There is alſo another reaſon why the force of gravity ſhould be more diminiſhed by the centrifugal force at the equator, than in any other place, which is this: The centrifugal force always cauſes a body to tend from the center of the circle in which it moves; and therefore it muſt act in direct oppoſition to the force of gravity at the equator, whoſe center is the ſame with that of the earth: but as the centers of all the circles parallel to the equator, are at ſeveral diſtances from the center of the earth, in every ſuch circle the centrifugal force acts obliquely againſt the force of gravity, and the more ſo, as the circle is nearer to the pole, and therefore cannot diminiſh it ſo much as it does at the equator.

Sir *Iſaac Newton* has proved, by a moſt ingenious method of computing, that bodies at the equator loſe $\frac{1}{230}$ part of the weight which they would have if they were placed at the poles; and has ſhewn, that the equatorial diameter of the earth exceeds the polar diameter, or the axis round which the earth turns, by about ſeventeen Engliſh miles and $\frac{1}{10}$; for if the equatorial parts of the earth, where the waters are lighteſt, were not ſo much higher than the polar parts, where they are heavieſt, the ſeas about the poles would ſubſide, and riſing at the equator, would overflow the lands thereabouts.

This law of gravitation is not confined to the matter of which our earth is formed, but is found to extend to all bodies that come any way under our obſervation. Sir Iſaac Newton has ſhewn, that the moon gravitates towards the earth, and is retained in her orbit merely by that force. And ſince the revolution of the moons round Jupiter and Saturn, and of the primary planets round the ſun, are phenomena or effects of the ſame kind with the revolution of our moon round the earth, he concludes, by the ſecond rule of philoſophiſing, that all theſe effects muſt proceed from like cauſes, and therefore that the moons of Jupiter and Saturn gravitate towards their primaries, and that all the primary planets gravitate towards the ſun. He has alſo ſhewed, that if one body attracts another with any force, with the ſame force does that other body attract it; ſo that the earth muſt gravitate towards the moon, the ſun towards the planets, and they all towards each other. He has proved likewiſe, that the attractive forces of theſe great bodies act according to one univerſal and invariable law, which is, that every two of them attract each other with forces that are directly as their quantities of gravitating matter, and inverſely as the ſquare of the diſtance between their centers.

Sir Iſaac Newton's great diſcovery conſiſts in his having proved, that the well-known power which we call gravity, acting throughout the ſolar ſyſtem, according to the law above mentioned, preſerves the planets and comets in their motions round the ſun; and that this force is fully ſufficient to account for all the irregularities of the lunar motions, for the retrogreſſion of the equinoctial points, and for the tides in our ſeas, whoſe waters gravitate towards the moon.

All this he has done by ſhewing, from mathematical calculations, that this force, acting on thoſe bodies, muſt neceſſarily produce ſuch effects and appearances, as exactly correſpond with thoſe which, the beſt obſervations aſſure us, do really take place in nature.

namely, if a bar of metal be fixed in a vertical direction, and heat be by any means applied to the middle of it, this heat will be communicated to the upper part of the bar, when the temperature of the lower part is ſcarcely altered.

Light muſt be acted on by a power in a direction contrary to the principles of gravitation; for as all bodies near the earth gravitate towards the earth, ſo do bodies in the heavens gravitate towards the ſun. But a flood of matter is ſent off every moment from his orb, in a direction oppoſite to that of the gravitating body, and this in ſo large a quantity, that no ſpace, however ſmall, could be aſſumed within the ſolar ſyſtem, where the point of a needle could be oppoſed to the ſun, without ſtopping ſome thouſands, or millions, of the particles thus ſent from him.

Still gravity may be conſidered as the combining cement, the operative ſpring of the mighty frame: urged by this principle, the rivers circulate with a never-failing current; it confines the ocean within it's bounds, and the planets within their orbits; thus the ſame force, which determines the fall of a ſtone, is one of the ruling principles of the heavenly motions; thus every where you find a wonderful mechaniſm! whoſe ſimplicity and energy give unceaſing tokens of the PROFOUND WISDOM of it's Author.

MIND AND MATTER ESSENTIALLY DIFFERENT.

Nothing in the action of matter can induce you to think, that it's action proceeds from any *ſenſe*, *perception*, *intelligence*, or *will*; or that *ſenſe* or *will* can be eſſential to matter; or that they are naturally involved or complicated with the actions of matter: for our ideas of the actions of matter are perfect and complete, though it were ſuppoſed, that ſenſe, perception, intelligence, or will, exiſted no where but in ourſelves.

Since we cannot doubt of the exiſtence of *ſenſe*, or *perception*, *intelligence*, and *will*, they muſt be the actions, operations, or properties of ſome kind of being, diſtinct from what is commonly called matter. There is nothing in the actions of motion, reſiſtance, or elaſticity, that raiſes in our minds any idea of ſenſe, perception, intelligence, or will; otherwiſe we could not conceive any machine, for example, a mill, without at the ſame time conceiving that it may have ſome degree of ſenſe, or perception, or intelligence, or will.

There is nothing then in the idea of the actions of matter, by which the parts of it can form themſelves into any kind of regular ſyſtem, with any *view to ſerve any purpoſe or end;* neither is there any thing in any ſyſtem of matter that we know, which neceſſarily ſuppoſes an exiſtence of that ſyſtem, or without which we cannot imagine matter to exiſt. We cannot conceive any thing eſſential to matter, whereby ſuch a quantity of matter (for example) muſt exiſt in that part of ſpace, where the ſun now exiſts, that it ſhould contain ſuch a proportion of reſiſting matter, and ſuch another proportion of light; that it ſhould be of a globular figure, &c.; or why one part of matter ſhould be collected and placed in ſuch order, as to form an animal; another part in ſuch another order, as to form a vegetable or plant. If there be nothing in the actions of matter to do this, then it muſt be done by ſomething different from matter.

We have no idea of ſubſtances; we have as little knowledge of the ſubſtance of material beings, as of intelligent ones; we have no idea of the thing in which the power of reſiſting, or of moving, or of re-acting, ſubſiſts; as little as we have of the being in which intelligence ſubſiſts: but we may have ideas of the actions or operations of intelligence, as we have of the actions of matter, or as we have of motion or reſiſtance.

The eſſential or characteriſtic diſtinction between the material agent and the intelligent agent is this: the material agents act always uniformly, and in all directions; they have *no power* in themſelves to increaſe their force of action, or to determine it to one direction more than to another; all alteration in their action, or in the direction of them, is made by ſomething external, which for that reaſon is called an efficient cauſe; they have *no will, purpoſe, view, or deſign in their action*: but the intelligent being determines and directs it's own actions, by the purpoſe, deſign, or view which it has, and therefore it's actions are ſaid to be determined or directed by final cauſes, and this direction by final cauſes is called the will; therefore in all actions of intelligent beings, which are likewiſe called moral actions, the intention, purpoſe, or will, is principally to be conſidered. This is the guiding principle in morality, policy, and religion.

The actions of intelligent beings cannot be the object of mathematical inquiry; for quantity, and the ratios of quantities, are the ſole object of mathematics; but there can be nothing of quantity in deſign, intention, or will; therefore, any inquiry into the actions of an intelligent agent muſt be on different principles from what are uſed in an inquiry into the actions of matter: but frequently our ideas ariſe from the complicated actions of intelligent and material agents, in which caſe a mixture of mathematical and metaphyſical principles become neceſſary in our inquiries.*

" To perceive, to compare, to deſire, to will, to feel pleaſure and diſpleaſure, require a ſimple ſubſtance, which muſt repreſent to itſelf things which are diſtant and ſeparated, collect things which are ſcattered, and compare things which are different. All that is ſpread over the wide ſpace of the corporeal world preſſes itſelf here together, as it were, into a point, to make out a whole; and what is paſt is in the preſent moment brought into contact with that which is to come. Here is neither extenſion, colour, motion, reſt, ſpace, nor time, but an active being which repreſents to itſelf extenſion and colour, motion and reſt, ſpace and time, combines, ſeparates, compares, ſelects, and poſſeſſes a thouſand other capacities which have no relation to extenſion or motion, attraction or repulſion. Pleaſure and diſpleaſure, deſire and averſion, hope and fear, are no change of place of little atoms. Modeſty, benevolence, philanthropy, the charm of friendſhip, and the ſublime feeling of piety, are ſomething more than the agitation of the blood, and the beating of the arteries, with which they are uſually accompanied; nor can they ever be confounded together but by ignorance, folly, and infidelity."

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* Colden's Principles of Action in Matter, p. 158.

LECTURE XXV.

THE OPINIONS OF THE ANCIENTS CONCERNIN MATTER, AND OF MATERIALISM.

HAVING given you an account of the prope ties that are eſſential to matter, and of th force of gravitation ſo univerſally acting thereo I ſhall now endeavour to give you ſome idea the opinions of the ancients on *matter*;* theſe a not only highly intereſting in themſelves, but eve throw much light on the phyſics of the moderns.

They conſidered the *viſibility* of matter not neceſſary conſequence of it's *creation*, but to ari from it's *formation*. The ſmalleſt particles matter in ſolution are inviſible; thus a miner water ſtrongly impregnated with iron, is *clear* an *tranſparent* as any other water, though the part cles of the metal are copiouſly diſtributed throu the whole body of the fluid. As ſoon as th begin to concrete into maſſes by the addition of aſtringent, they *ſhew* themſelves, the water becom turbid, and by degrees turns as black as ink: l the reverſe of this operation, ink, with the additi of a ſtrong acid, will be turned into a colourl water. The *ſky*, though retaining a very lar quantity of water, preſerves it's clearneſs ſo lo as the moiſture is in a ſtate of ſolution; but as ſoon as the atoms of water are aſſembled together in maſſes, by means of ſome change in the temperature of the air, the ſky is overcaſt, and becomes dark and cloudy. The viſibility therefore of matter commences when it concretes and aſſumes a form; ſo long as it is formleſs, it is alſo inviſible. The *chaos*, in it's primæval ſtate, is ſaid to have been *without form*, or according to the Greek verſion *inviſible*; and the ſcripture, referring elſewhere to this condition of the world, tells us, that *things which are* NOW *ſeen were not made of things that do appear*; in other words, viſible forms were compoſed of inviſible atoms.

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* See the works of Mr. Harris, particularly the Philo phical Arrangements, and the Hermes; Sydenham's Pla Jones's Phyſiological Diſquiſitions; Petvin on Mind; M boddo's Ancient Metaphyſics; R. Clarke's Series of Lette Berrington's Immaterialiſm delineated; Cudworth's Intel tual Syſtem, &c.

Though matter is no object of our knowledge but in it's *formed* ſtate, we are nevertheleſs obliged to underſtand a kind of *firſt matter*, out of which all the viſible forms are raiſed, and into which they return at their diſſolution.

The ancient philoſophers carried their ſpeculations on this ſubject very far, ſuppoſing the firſt matter to be homogeneous, and accommodated to the formation of all ſorts of bodies indifferently.

Matter they conceived to be that elementary conſtituent in compoſite ſubſtance, which appertains in common to them all, without diſtinguiſhing them from one another. Every thing generated or made, whether by nature or art, is generated out of ſomething elſe, and this ſomething elſe is called it's *ſubject* or matter; ſuch is iron to the ſaw, ſuch is timber to the boat.

Thus matter was conſidered as an homogeneous being, the common baſis or element out of which all bodies were formed; it therefore implies a *privation* of all *form*, and a *capacity* to every form, as is the braſs to the ſtatue, the marble to the pillar, the timber to the ſhip, or any one *ſecondary matter* to any one *peculiar* form; ſo is the firſt and *original matter* to all *forms* in general, poſſeſſing no quality whatever except that of being paſſive in receiving any ſort of form; a notion framed by rejecting every bound that can be ſet to ſubſtance, and every poſitive attribute except the bare capacity of receiving ſome form or other.

Such is that ſingular being which thoſe philoſophers (ſays Mr. Harris) who are immerged in ſenſible objects, know not well how to admit, though they cannot well do without it; a being which flies the perception of every ſenſe, and which is at beſt even to intellect but a *negative* object, no otherwiſe comprehenſible than either by *analogy* or *abſtraction.**

This inviſible and formleſs being, the univerſal recipient of all forms, was by ancient poets and mythologiſts pourtrayed by Saturn, who ſignified this hidden and ſecret ſtate of matter, out of which all viſible forms are generated, and into which they ſink again, whence he is reported to have devoured his own children. The decay of forms being the work of time, Saturn had alſo the name *Kronos.* He is fabled to have been married to Ops, becauſe matter when united to form becomes *viſible*; and Ops is called the mother of gods, becauſe their gods were the elements in a formed ſtate, and were no objects of worſhip to them till they became viſible. The ſame idea you will find under the allegory of Proteus, or original matter the receptacle of all forms, who is ſaid to be diſcovered by Eidothea his daughter, by her leading him forth out of capacity into actual form.

It is well obſerved by Plato, that while we are in this ſtate of exiſtence, ſlumbering and as it were dreaming, we cannot ſee the truth of things except by ſhadows, as we ſee them in our ſleep; and it is a certain truth that we do not know the ſubſtance or eſſence of any of the works in nature, but only ſome of their qualities and properties; for example, all that we know of any animal or vegetable is, that it has ſuch or ſuch qualities, and by theſe we define it; but what is the ſubſtance of it, and what is the hidden eſſence producing all thoſe viſible qualities, we cannot tell.

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* *Abſtraction* makes it ſtand under the ſame character to the touch, as darkneſs ſtands to the ſight, ſilence to the hearing. We cannot be ſaid to ſee the one, or hear the other: and yet, without the help of thoſe two ſenſes, we could have no comprehenſion of thoſe two negations, or ſenſible privations.

It is the ſame with *body*; it would ſeem that this were only the outward cover, that there was ſome ſuch primary matter as has been mentioned common to all viſible things, and becoming the ſubject of the natural or ſublunary elements. The conception of an original matter, and which can only be denominated from it's capacity or aptitude to receive all forms, appears eſſential to any rational theory of the conſtitution of things.

To this principle we muſt add *form*, which draws matter as it were out of it's chaotic ſtate, and impreſſes it with a diſtinctive character, and renders it an object of the ſenſes; not that there ever was actually any matter without body, or body without quality, but they may be ſo ſeparated by the mind for the better contemplation of the well-ordered generation of things.

The firſt form that matter aſſumes is *extenſion*, by which it's parts become contiguous, that is, joining to one another, and having one common boundary which is threefold, length, breadth, and depth; matter triply extended, is what may be called pure and original body; extenſion enters into the primary conception of body; but yet extenſion, though the inſeparable quality of all bodies, is itſelf preceded by ſomething as it's ſource or principle of eduction, without which it would not exiſt. Thus a point or unity is the eſſential conſtituent of a line, the line of a ſuperficies, the ſuperficies of a ſolid; ſo that unity is the eſſential principle of extenſion, which is an effect ariſing from the arrangement of units or points, as number is ſuppoſed to flow from the ſucceſſion or conjunction of units.

Body, even under this character, is ſtill too vague for ſcientific contemplation; it's extenſion muſt be bounded, but the bound or limit of body is *figure*, which becomes the next form after extenſion.

But matter thus extended and bounded by figure is ſtill ſomething vague and indefinite, ſcarce an object for the natural philoſopher; it is only body *mathematical*; but this not being ſufficient for the purpoſes of nature, it muſt be inveſted with other forms; not only the *external* form muſt be duly bounded, but the *internal* parts muſt be duly *organized*, that is, the materials muſt be properly *adjuſted*, *diſpoſed*, and *arranged*, which gives riſe to body *phyſical*.

Theſe three, extenſion, figure, organization, were conſidered as ſufficient to characterize phyſical body; figure having reſpect to it's external, organization to it's internal, extenſion being common to both.

From a variation in theſe *univerſal* and primary forms, may ariſe moſt of thoſe ſecondary forms, uſually called qualities ſenſible, being the proper objects of our ſeveral ſenſations; ſuch are roughneſs and ſmoothneſs, hardneſs and ſoftneſs, the tribes of colours, ſavours, and odours.

Thus *matter*, the elementary conſtituent of every compoſite ſubſtance, is a chaotic maſs void of every property, but capable of becoming the baſis or recipient of every form; it is therefore itſelf *formleſs*, *imperceptible*, and *paſſive*. But of this univerſal and common ſubject, *body* is produced by the introduction of *forms* or *qualities*, which inveſt and characterize particular portions of it; as in the works of human art, out of one common maſs the ſkill of the ſtatuary educes thoſe beauteous forms, in which a Venus or a Hercules loves to charm and aſtoniſh us.

The form or eſſence of every natural ſubſtance, or in other words, *it's ſyſtem of internal qualities*, extends itſelf *outwardly* every way from *within*; and as it muſt neceſſarily ſtop ſomewhere, ſo according to the different points at which it ſtops in it's *evolution*, it communicates to each ſubſtance a different and peculiar figure. Hence the *true character* of every natural and ſpecific figure, which is not to be conſidered as a mere ſurface, but the bound to which the *internal* eſſence or form every way extends itſelf, and at which it terminates.

Hence of all the *external* qualities there is none ſo characteriſtic as *figure*; it is a kind of *univerſal ſignature*, by which nature makes known to us the ſeveral ſpecies of her productions; the primary and obvious teſt by which we pronounce this a vegetable, and that an animal; this an oak, that a lion.

If you proceed from natural ſubjects to works of art, you will find that figure is *almoſt* all that *art* is able to communicate; it is to this that the painter arrives by *addition*, the ſculptor by *detraction*, the founder by *fuſion*, and the ſtucco artiſt by *moulding*. Even when you contemplate the tools of art, you will find the figure a principal circumſtance. It is from this that the ſaw divides, the hammer drives, and the pincers extract; and it is from their figure, not their materials, that they derive their character and name.

All *natural* and *artificial* things *partake* of *form*, and *partake* alſo of *matter;* form is derived to them from *mind; ſuperficial* form is derived to the works and performances of *art*, from the *minds* of human artiſts; *internal* and *eſſential* form is derived to the works and operations of nature from the *Divine Mind.* For though the common *ſubject matter* of all *external* forms or beings be in itſelf *boundleſs*, and *void* of all form, yet it is every where bounded and impreſſed with form by the great CAUSE of *all things*, from whom proceeds every *form*, the *bound* of every diſtinct being, and the whole of it's eſſence or eſſential nature. The ancients allowed the neceſſity of a ſpiritual agency to animate and produce form, that it might be conjoined to the Divine Being, and ſubjected to the Divine Providence; hence matter received that ſpecific form, which is moſt agreeable to the order and beauty of the univerſe. Through the whole univerſe we ſee matter bearing the *marks of mind*, and every where impreſt with the prototypes of *genus* and *ſpecies*; we ſee all *animals* continually ſeeking by natural inſtinct the *welfare* of their *own being*, the continuance of their *kind*, the preſervation of their offspring; and we feel ourſelves, in the rational part of our nature, charmed with the ſight of *beauty*, and ſmitten with the love of it; we feel our minds urged on to inquiries after *truth* as it were by a *preſenſation* of it's ſupreme beauty, and a *preconception* of it's being to us a good; impulſes ſo ſtrong, that however often we may be diverted from ſuch inquiry by the neceſſities of the body, by fancy, or paſſion, or the deſire of imaginary good, yet when left to the exerciſe of it's own faculties, unhindered and undiſturbed, the mind is always in purſuit of it, tracing it through the natural and neceſſary connection of ideas; and when it has found it, is never driven away from this attachment ſo long as it turns the inward eye thereto. Thus our *view* of all the forms of outward nature, our *experience* of the diſpoſition of all animals, and the *conſciouſneſs* of our mental feelings, ſentiments, and actions, conſpire to evince to us the ſpiritual and divine agency that runs through the whole.

From form and figure, the ancients proceeded to another and higher form, the *life*, or animating principle, which was conjoined in many inſtances to matter: theſe are forms which characterize not by *viſible* qualities, but by their reſpective *powers*, *operations*, and *energies*. As is the piper's *art* to the pipe, the harper's to the harp, ſo is the *ſoul* of the lion to the *body* leonine, the ſoul of man to the body human.*

It is to this diverſity of ſpiritual power in theſe, that the diverſity of the organization in the corporeal world has reference. That ſtrong and nervous leg, ſo well armed with tearing fangs, how perfectly is it correſpondent to the fierce inſtincts of the lion! Had it been adorned, like the human arm, with fingers inſtead of fangs, the *natural energies of a lion* had been all of them defeated. That more delicate ſtructure of an arm, terminating in fingers ſo nicely diverſified, how perfectly does it correſpond to the pregnant invention of the human ſoul! Had theſe fingers been fangs, what had become of poor *Art*, that by her operations procures us ſo many elegancies and utilities? It is here we behold the harmony between the viſible world and the inviſible, between the active and the paſſive, between the living and the lifeleſs. The whole variety in *bodies*, as well natural as artificial, is ſolely referable to the *previous* variety in theſe their animating eſſences; it is for the ſake of theſe they *exiſt*; it is by theſe they are *employed*; and without them they would be as uſeleſs as the ſhoe without a foot.

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* Thoſe, ſays the *ſtagyrite*, who adopt the notion of placing *any* ſoul in any body, talk as abſurdly, as if a perſon was to ſay, the carpenter's art might enter into a muſician's pipe: now it is neceſſary every art ſhould uſe it's proper inſtruments, and every ſoul it's proper body.

As nothing can become known by that which it has not, ſo it would be abſurd to deſcribe theſe ſpiritual powers by *any viſible or other qualities, the objects of our ſenſations.* The ſculptor's *art is not figure*, but it is that through which figure is imparted to ſomething elſe. The harper's art is not *ſound*, but it is that through which ſounds are called forth from *ſomething elſe.* They are of themſelves no objects either of the ear or eye; but their nature is underſtood in this, that were they never to exert their *proper energies* on their *proper ſubjects*, the *marble* would remain for ever *ſhapeleſs*, the *harp* would remain for ever *ſilent.*

It is the ſame in natural being; the *living eſſence* of a natural being is neither it's organization, nor it's figure, nor any other of thoſe inferior forms, which make up the ſyſtem of it's viſible qualities; but it is he power, which not being that organization, nor that figure, nor thoſe qualities, is *yet able* to produce, preſerve, and employ them. It is the power, which departing the body, ceaſes to live, and the members ſoon paſs into putrifaction and decay. It is *in mind* that forms exiſt, before matter can receive them; it is *from mind*, when they adorn *matter*, that they primarily proceed; ſo that whether we contemplate the works of art, or the more excellent operations in nature, all that we look at as *beautiful*, or liſten to as *harmonious*, is the *genuine effluence or emanation of mind.*

Theſe tranſcendant objects are of an origin ſo truly *mental*, that nothing but *mind or intellect can recognize or comprehend them*. Hence, if this intellective faculty be wanting, as it is in inferior animals, or be unhappily debaſed, as too often happens to our own ſpecies; though their *ſenſitive* organs may be exquiſite to a degree, yet are ſuch to ſuch objects, as if they had no organs at all. *Eyes have they, and ſee not.*

From this view of things, we ſee, that *means* do not lead to *ends*, but *ends* lead to *means*; that it was not the organization of the ſheep's body which produced the *gentle* inſtincts of the ſheep; nor that of the lion's body, which produced the *ferocious* inſtincts of the lion; but becauſe in the *divine* œconomy of the whole ſuch ſpiritual principles neceſſarily exiſt, they are cloathed with ſuch bodies as are agreeable to their reſpective nature, and fit for their proper buſineſs in this world.

But ſtill all the different capabilities of mind and matter are derived from that ALMIGHTY BEING, who is the ſource of all capacity, as well as of all power; who hath diſtributed amongſt all animals, both the *irrational* and the *rational*, ſuch *capacities*, *abilities*, and *energies*, as may fit them for being ſalutary and ſerviceable; and who has impreſſed on matter ſuch diſtant characters of his own beauty as the ſubject will bear; as in the glory of the heavens, in the ſymmetry of form, in the harmony of ſounds, and in the elegance of colours, in the elaborate texture of the ſmalleſt leaf, and in the infinitely fine mechaniſm of ſuch inſects and minims of nature, as are ſcarce viſible to the eye of the cleareſt diſcernment.

From the foregoing principles, which throw light on all the objects of mind, make them viſible, as it were, to the mind's eye, and at the ſame time pour light into that eye, to ſee thoſe objects, the ancients concluded the DIVINE BEING to be GOODNESS ITSELF, and TRUTH ITSELF; and that theſe were continually diffuſed into all things, in proportion to their ſeveral capacities. Under theſe characters, the moſt obvious to be perceived, they conſidered him as the cauſe, both final and formal, of all that *good* which is enjoyed by beings who are capable of any enjoyment, and of all that *beauty* and *truth* which is enjoyed by thoſe who have a ſenſe of beauty and truth.

" But they even go farther than this. The ſages of antiquity affirm, with great appearance of truth, and ſtrength of argument, that we have a principle of exiſtence within us, infinitely more intimate, more valuable and durable, than this expanſe of heaven and earth, this incloſure of fleſh and blood, or any ſpecies of life and health that can be ſubject to mortality; that this principle of exiſtence is of *divine original*, *incorruptible*, *unperiſhable*, a *fount* that muſt flow *for ever*, a *flame* that cannot be extinguiſhed; that the virtues are it's treaſures, it's enjoyment, it's beauty, and illumination; that theſe conſtitute the man, all that can properly or inherently be denominated himſelf, and all that deſerves his regard or attention."

" Thus far ſtretches the doctrine of Pagan philoſophy; and conformably thereto, it's votaries rejected the world, with all it's enjoyments, and even boaſted a ſuperiority over poverty, calamity, pain, ſickneſs, and death."

" But if to this we add ſomething of that REDEEMING WORD, which brought life and immortality to the fulneſs of their light, and the weight of their glory; all that is temporal fades and vaniſhes away in the compariſon with any article that is eternal: the goods of this world are no longer to be reliſhed, nor it's evils to be feared: the preſent is ſunk, and loſt in the greatneſs of the future; and poſſeſſion is caſt behind us, in reaching after the immenſity of that for which we hope."

"Nothing becomes conſiderable, nothing of eſtimation, ſave ſo far as it conduces to the purchaſe or acquiſition of ſome article or degree of goodneſs; ſome of thoſe benevolences, thoſe charities, thoſe affections, thoſe elegancies of elevated humanity, which the great apoſtle to the gentiles prefers even to the graces of faith and hope; and which, he ſays, "cannot fail," but muſt endure for ever, when faith is ſwallowed up of viſion, and hope of enjoyment; when every will ſhall be ſubdued to the WILL OF GOOD TO ALL; when OUR SAVIOUR will take in hand the reſigned chordage of our hearts, and will tune them, as ſo many inſtruments, to the ſong of his own ſentiments, and will touch them with the fingers of his own feelings. Then the happineſs of each ſhall multiply, and overflow in the wiſhes and participation of the happineſs of all."

OF MATERIALISM.

From contemplating the beautiful opinions of the ancients, I unwillingly turn to the unpleaſant taſk of pointing out the errors of ſome modern philoſophers, who, from falſe views of the *nature of matter*, and from ignorance of the principles of *mind*, have adopted the dire and gloomy ſyſtem of *materialiſm*. If this ſyſtem be true, if our ſoul be mortal, reaſon is a dream, and virtue loſes all the ſplendor which makes it godlike in our eyes. If you delight in friendſhip, if you reſpect virtue, and are charmed with beauty and per-

organs; thus reducing all the intellectual and actual faculties, to motions of the brain, of which the *ſoul* is only a *ſpectator*, though, by a continual illuſion, ſhe attributes them to herſelf. But a more modern materialiſt has thought it would be ſimpler to make the *ſcene* it's own *ſpectator.*

In order to effect this, he endeavours to render thoſe ridiculous who aſſert, that the ſoul and body have no property in common, though they have a mutual action on each other, and are capable of an intimate communication. The ridicule thrown upon this opinion may divert the reader's attention; but it gives no ſtrength to the arguments of the materialiſt. For we have no objection to allow him, that *thinking ſubſtances*, and *phyſical ſubſtances*, have very great relations, and that they have no *repugnance*, but a certain *correſpondence* the one to the other. The body being a viſible agent in all we do, has indeed made ſome weak heads imagine, that we are nothing elſe but body; as from the ſame want of thought, ſome have concluded, that there is nothing beſides the material world, becauſe nothing elſe is obvious to their eyes.

The man of matter, penetrated with the idea that he ſhould reconcile all the world to materialiſm, if he could *exalt matter;* and conceiving that what was ſuppoſed to be deſpicable and abject therein conſiſted in it's *impenetrabily*, and it's *inertia;* he has endeavoured to deprive it of theſe properties, but in vain; for *matter*, even coming out of his own hands, is as *impenetrable* and *inert* as that of *Newton.*

It is rather ſingular in our materialiſt to begin his work, with expreſſing his veneration for the great man I have juſt named, propoſing to adopt his rules of philoſophizing, and complaining

of

That it is not immortal. 3dly, That he derives his hopes of ſurviving the grave, from the general reſurrection of the dead. 4thly, That there is no ſuch exiſtence as a ſoul between the hour of death and the general reſurrection, when the man reſum e the ſame *organical ſtructure* of the *brain.* Now the revelation of CHRIST conſiders the ſoul as of a *diſtinct* nature from the *body*, and as exiſting after death. From *revelation*, therefore, this author can derive *no hope* of ſurviving after the grave, if the ſoul becomes extinct with the body.

But further, the myſtery opened in the goſpel, relates to quite *another kind* of life in the ſoul, than that which is implied or conſiſts in it's *bare immortality.* For *immortality* conſidered in itſelf, as a *phyſical neceſſity* of it's continuing in life for ever, may as well be a curſe as a bleſſing, and have heaven or hell for it's portion. But this is not the *life* and *immortality* that the goſpel preaches. It leaves this *natural* immortality, which belongs as well to the ſpirits of darkneſs as to men, as wholly untouched as it does the original of the alphabet.

The *immortality* of the goſpel is not ſo called on account of it's *eternal duration*, but becauſe the ſoul is thereby *eternally freed* from thoſe evils and errors which would prevent it from enjoying the light and life of heaven. But though the *natural* immortality of the mind is never expreſsly mentioned, or aſſerted in the goſpel, yet is it *fully proved* therein, becauſe *unavoidably* ſuppoſed, and *neceſſarily* implied in and by the *plain* and *open* doctrine of the goſpel.

In the ſyſtem of Dr. Hartley, the *ſoul* was rendered purely paſſive; the *memory*, the *judgment*, the *will*, and the principle of all voluntary motions, are placed in the *phyſical* properties of the is a contradiction, it follows, that the atoms muſt be *undivided*; and this is all here meant by *hardneſs*. The materialiſt ſays, that, without a *power*, the parts of atoms would ſeparate themſelves, and be diſperſed; but I ſay, that without a *power*, they can neither be ſeparated nor diſperſed; and you can be under no doubt, which of theſe propoſitions is moſt conformable to the *Newtonian rules of philoſophy*.

Again, becauſe the materialiſt has thought proper to diveſt matter of *ſolidity* and *inertia*, is it therefore entitled to the powers of *ſenſation* and *thought?* Becauſe he chuſes to define matter *a ſubſtance poſſeſſed of the property of extenſion, and of powers of attraction and repulſion*, are we to conclude that there is no longer any reaſon to ſuppoſe in man two diſtinct ſubſtances?

"If there be any truth in late diſcoveries in philoſophy (ſays this man), *reſiſtance* is in moſt caſes cauſed by ſomething of a quite different nature from any thing *material* or *ſolid*, viz. by a *power* of *repulſion*, acting at a diſtance from the body to which it has been ſuppoſed to belong; and in no caſe whatever can it be proved, that *reſiſtance* is occaſioned by any thing elſe." He relates thoſe experiments which ſhew, that there is a conſiderable difficulty to bring bodies to a real *contact*; thoſe on the dilatations and condenſations of bodies, which prove that their parts are not ſo cloſe as they might be; and conceiving that the particles can never be brought into real contact, he concludes with ſaying, "That there is nothing real in matter but attractions and repulſions; and that theſe oppoſite *powers* relate only to certain points of ſpace, points *mathematical*, without *ſolidity*, and which can only be conſidered as the place to which the power is referred."

I muſt confeſs with Mr. de Luc, that if any one can comprehend what theſe *powers* are which have *extenſion*, and which are ſtill only *mathematical points*, and which attract and repel each other, and can conſider ſuch an account as a ſolution of the difficulties concerning MATTER, he has either a *ſenſe* more or leſs than I have. *Newton* had ſeen theſe repulſions, or the reſiſtance that is found in bringing certain bodies into perfect *contact*; but he conſidered them ſimply as the effect of an *elaſtic fluid* ſurrounding them, of which *air* and *fire* afford us palpable examples. He alſo declared expreſsly, that he conſidered *energy without ſubſtance as an abſurdity*. So far was he from thinking that the *reſiſtance* made by bodies in approaching each other was invincible, that on the contrary he proved by experiment, and he explained by his elaſtic fluid, that after the repulſion was conquered, the effect of the proximity was a ſtrong adheſion of the bodies produced by the exterior *preſſure* of the ſame *elaſtic fluid*.

Not to inſiſt that the *powers* aſſumed by our materialiſt are entirely *hypothetical*, and *contrary* to the *general agency* in nature, and therefore *inadmiſſible*, it will be eaſy to prove, that even his own account of matter eſtabliſhes principles contrary to his wretched ſcheme; and you will find his matter as inert as our's; for the idea of impenetrability only ſuppoſes that two extended ſubſtances cannot be in the ſame place at the ſame time. Now the materialiſt muſt give the ſame property to his *ſphere of powers*, becauſe he ſtill conſiders *extenſion* as neceſſary to his matter; his ſpheres therefore muſt be impenetrable, one cannot be in the place of the other at the ſame time, for this alone is the *phyſical* idea of impenetrability, which has nothing in common with hardneſs. In whatever manner we conceive *matter*, it may be compreſſed, divided, ſubdivided to infinity, and yet continue impenetrable.

It is the ſame with inertneſs: we ſhall find his particles poſſeſſed thereof as well as our's; for what is inertia but *matter* continuing at *reſt* until ſome cauſe puts it in motion? Can the materialiſt refuſe this property to his *ſphere of powers?* They have relation to ſpace, they occupy *place*, and are *moved*; conſequently all the true notions of motion are as applicable to theſe as to any other conception of matter: it is as *inert* as our's, and after all his endeavours to ſeparate the ideas of *impenetrability* and *inertneſs* from matter, he has ſtill made *matter impenetrable* and *inert*. They are eſſential properties of that *ſubſtance* which compoſes the *phyſical world*, which no effort of the imagination can ſeparate from theſe ſubſtances.

But the matter of this man is not only inert and impenetrable, but it is alſo poſſeſſed by his own confeſſion of properties *quite of a different nature* from any thing *material*; ſo that after endeavouring to prove, that *matter* was the only ſubſtance entitled to exiſtence, that it was the *cauſe* of all appearances, yet to account for the various phenomena he is obliged to give us ſomething of a *quite different nature* from any thing *material*; this *immaterial* ſomething is the *power of repulſion*, the property of all *matter*. Is ſuch a power really different from every thing *material?* or can matter act by *immaterial* powers? So rooted is the averſion of our materialiſt to mind, ſuch his *pneumatophobia*, that he will ſuppoſe or adopt any thing ſooner than admit the agency of mind.

He tells us, we conceive *ſpirit* and *body* to be poſſeſſed of no *common property*. We aſk him where he finds any thing *common* between *perception* and the powers of *attraction* and *repulſion*, that is, between the ſentient and corporeal powers? Nay, what is there common between the attractive and repulſive powers themſelves? We inſiſt that ſenſation, and the powers of attraction and repulſion, as likewiſe theſe two reſpectively, *are as oppoſite*, and as far removed from the poſſeſſion of *any common property*, as thoſe very powers which as immaterialiſts we attribute to matter and ſpirit.

It is *mind* that ſees the difference not only between black and white, bitter and ſweet, but (which no ſenſe is equal to) the difference between black and bitter, white and ſweet, and the various tribes of *heterogeneous* attributes. Nor does it ſhew this ſupremacy in theſe recognitions only; but likewiſe when *at one and the ſame view* it recogniſes objects of *ſenſe* and *intellect* united, as in the caſe of ſyllogiſms made of propoſitions particular and univerſal.

This *joint recognition* of things multiform, contrary, and heterogeneous, and that by the *ſame faculty*, and in the *ſame undivided inſtant*, proves in the ſtrongeſt manner that the mind is immaterial; for body is incapable of ſuch a ſimple and perfect unity.

But leaving theſe and many other conſiderations, let us ſee whether the matter of the materialiſt, ſuch as he imagined himſelf, will ſeem fitter for becoming a percipient *being*. To him indeed it appears eaſy, for ſince the *thing* that we call *matter* conſiſts only in *powers*, there is nothing to prevent it's having the powers of *perception*; but a little conſideration will ſhew, that the difficulty is more inſurmountable in his ſyſtem than in any other.

For as long as we conſidered a *ſubſtance* to which the powers of attraction and repulſion were attributed, there remained this obſcure idea, "that a ſubſtance might be endowed with many kinds of powers, and it would be neceſſary to diſcuſs this queſtion; but in the preſent caſe there is no room for diſcuſſion; if a *power* can be conceived *without ſubſtance*, it will be itſelf the *whole being*. *A power of attraction* is a *power of attraction*, and can be nothing elſe. This claſs of *powers* form, according to our materialiſt, one part of *matter*; the remainder is formed of powers of repulſion, which can be nothing elſe but powers of repulſion. If therefore he wants *power of perception*, he muſt make it, his matter has no ſuch power.

"In what kind of *principles*, ſimple or compounded, does he ſuppoſe even the *powers* of *attraction* and *repulſion* to reſide?"

"Does he think the ſame *numerical* ſubſtance can at the ſame time poſſeſs the *attractive* and *repellent powers*; i. e. that the ſame body can be at once *attractive* and *repulſive*? By *repulſion* all abſolute approach or *contact* is impeded: by *attraction*, bodies, when at a diſtance from each other, tend to mutual approach."

"Now as he declares theſe powers to be *eſſential* to *all* matter, all matter is ever tending to approach, and ever receding from all matter; A and B always going to, and, at the ſame inſtant, always going from each other!!!*

But why does the materialiſt ſuppoſe the *phyſical world* to be compoſed only of ſmall ſpheres of *attraction* and *repulſion*? It is this: on examining the various phenomena one by one, he thinks, that at the end of his analyſis, he finds nothing remaining but *attractions* and *repulſions* without SUBSTANCE. The ELEMENTS are therefore only *attraction* and *repulſion*, when the *phenomena* indicate nothing but *attraction* and *repulſion*; but when the phenomena indicate *ſenſibility* and *ſelf-conſciouſneſs*,

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* Berrington's Immaterialiſm Delineated, p. 229.

neſs, what are the ELEMENTS? Are they ſtill only *attraction* and *repulſion?* Is there no *faculty* of *perception* in the ingredients?

Our materialiſt feels no force in this objection; with him it is no more "than if it were ſaid, that no *harmony* could reſult from a harpſichord, becauſe the ſingle notes, ſeparately taken, can make no *harmony*." The man who can thus anſwer does not underſtand the nature of the proof; for what is HARMONY? it is *the union of two or more ſounds*, of which the whole is agreeable to the ear. It is therefore of the *eſſence* of *harmony not to be* in each of it's *elements*, as it is of *number not to be* in *unity*.

Mr. Berrington purſues this ſtill further: *harmony* in muſic ariſes from a number of modulated ſounds; *proportion* alſo or *ſymmetry* in architecture ariſes from the appropriate arrangement of materials; but *each ſound* taken ſeparately is *void of harmony*, as each ſtone in a building is diveſted of proportion. In the *external* objects themſelves, what have you, but detached and inſulated ſounds, detached and inſulated ſtones only riſing in a definite order of ſucceſſion and co-exiſtence? What is it then that gives exiſtence to the charms of harmony and proportion? That *being* alone which, gifted with *percipient* and *comparing* powers, can take in ſuch various tones and various parts, can compare them together, and therein perceive accord and proportion. This *exalted power* through the wide ſtretch of nature is alone capable of giving exiſtence to ſuch unſubſtantial forms. Harmony and ſymmetry are mere effects of compariſon, all their reality is derived from man.

But if the *brain* were the ſole ſubſtance on which ſuch impreſſions are formed, harmony would be eternally excluded from the material univerſe; for on that ſuppoſition a thouſand diſtinct vibrations in the nervous ſyſtem could no more give it reality than it could be raiſed by the ſound itſelf. Were each particular ſounding particle to act on the ear, or each part in an edifice on the eye, and proceed no further, what would be the effect? Evidently only this; the moſt regular and finiſhed ſtructure would remain as an heap of ſand, and the *airs* of an Arne be as unaffecting as the whiſtling of the wind. Juſt ſo muſt it be in the material ſyſtem, becauſe no *center* of union can exiſt therein, and conſequently no compariſon or juſt perception; therefore no harmony or proportion can take place: ſo that the materialiſt's own examples, adduced to prove that *perception* may belong to a whole ſyſtem, and not to it's component parts, directly make againſt him, and ſupport the immaterial hypotheſis.

Is there nothing real in *life*, ſays our materialiſt, becauſe each particle has not LIFE? It is not more eaſy to conceive the nature of *life*, than of perception. The *life* of the human body in one point of view may be conſidered only as an arrangement of organs put in action by the elements; but even in this loweſt view, like *harmony*, *life* is the reſult of the whole, and is not to be found in the component *elements*. In order that a watch may *meaſure time*, it is not neceſſary that each of it's particles or each of it's parts ſhould alſo *meaſure time*. In a word, theſe are only *properties* attached to the idea of *compoſition*; or to ſpeak more exactly, they are *reſults* not *properties*, *laſt effects* not *primary cauſes*, which are evidently different.

If the materialiſt had properly conſidered the examples he uſed, he would have found therein a full confutation of his own principles; as an inſtance, he affirms, " it may juſt as well be ſaid that *ſound* cannot conſiſt of a vibration of the air, becauſe

cauſe no ſound could reſult from the motion of a *ſingle* particle of that elaſtic fluid, as that perception cannot belong to a whole ſyſtem and not to the component parts." No one, I believe, ever aſſerted that the individual particles of air were not concerned in cauſing *ſound*, for each particle of the fluid which tranſmits the ſounds tranſmits a part, but too feeble to be perceived by our organs; it is from the number of theſe ſmall impreſſions that one reſults ſufficient to be perceived. Is not the ſentiment of light, which can only take place from a pencil of rays, produced, becauſe each particle has the faculty of exciting this ſentiment?

Much is uſually urged in favour of the *unity* of the *being that perceives*, and of the abſolute impropriety of attributing thereto any parts according to our idea of *parts* in *matter*. This reaſoning he conſiders as proving no more againſt the diviſibility of mind, than if we concluded, "becauſe a *ſphere* was *one* thing, that it was therefore indiviſible. It is true, he adds, that it is impoſſible to divide *one ſphere* into *two ſpheres*, but it may be divided into parts, ſo as to be no longer a *ſphere*. In the ſame manner the *ſyſtem of intelligence*, that we denominate the *ſoul* of *man*, cannot be divided into *two ſouls*; but it may be divided and diſſolved, ſo as no longer to form a SYSTEM *of intelligence*, *a* SOUL."

After this compariſon, in which he triumphs much, he adds, "If any one can define the unity of conſcience in a more favourable manner for the immateriality of the ſoul, he ſhall be glad to hear it, and pay it a proper attention." As the definition of this unity has been often and ſo well given; as every idea of parts affirmed or denied with reſpect to this *oneneſs* of the mind, is as abſurd as to apply thereto colour or taſte, it will be ſufficient to anſwer his argument in a manner ſomewhat ſimilar to his own, "that if any one can prove that *ſelf-conſciouſneſs* depends on a ſpherical, cubical, pyramidical, or any other material form, you may admit this faculty as depending on a phyſical whole."

Not tired with compariſons, our materialiſt elſewhere compares the *unity of the ſoul* to that of a collective number of moral beings, as of *ſtates* and *ſocieties*, which, though compoſed of ſeveral members, have a ſpecies of unity. Here, as in the compariſon he drew from ſound, the materialiſt is really pleading our cauſe, and this inſtance is ſtill far leſs to his purpoſe than the former; for as the *unity of man* can only be perceived and compared to itſelf, if this unity was a compound, each of the parts muſt have the *property* of the whole, that is, *ſelf-conſciouſneſs*. For the collective moral beings, to which the materialiſt compares us, have a common *unity*, becauſe each of the members has a unity of it's own.

The unity of conſciouſneſs is inſeparable from every mode of perception; whenever *I perceive*, or whenever *I think*, a ſentiment ariſes within me, which tells me that it is *I* that *perceive*, and *I* that *think*. Thus to *feel* is to be *conſcious*; *conſciouſneſs* tells me that *I* who now *am*, am the *ſame perſon* who *was* yeſterday, the day before, and ſo on; it connects the paſt with the preſent, and can only reſide in a ſpiritual undivided ſubſtance.

Having finiſhed my remarks on the notions of a modern materialiſt, I have only to regret the occaſion of them, and to hope that ere long the fictions, ſophiſtry, and errors which encompaſs his mind, may be removed, and that he may return to the faith once delivered to the ſaints. In the mean while, on our parts let us contemplate him with the greateſt compaſſion, remembering that diſcernment is alone clear and unerring in the SUPREME MIND; all whoſe ideas are *pure* and *perfect*, whoſe *power* is conſtant *energy*, and whoſe *eye* is *intellectual light* itſelf, unobſtructed, unbroken, and unclouded by any of it's objects. But the *eye* of *man's reaſon*, how ſhort-ſighted and weak it is; through what a *medium* of falſe *colourings*, and with what interrupted *glances* it diſcerns the few objects to which it is directed; and how frequently and how greatly *man's judgment* errs, is well known to every *fair mind*, who has had experience of her *particular* and *private* ſelf; and has converſed with *truth* and *right reaſon* intimately as with *friends*, yet *modeſtly* as a *diſciple* with his *teachers*, and *ſimply* as a *child* with his *natural parents*.

OF THE UNITY OF THE PERCIPIENT BEING.

As the *unity* of the percipient being is the argument at which materialiſts in general aim all their forces, knowing that, if this be allowed, their ſcheme falls to the ground of itſelf; knowing, that it is as it were an *egis* impenetrable againſt all their monſtrous endeavours to form the ſoul of man by an aſſemblage of material parts; I ſhall therefore endeavour to place it before you in different points of view, and in different manners; thus the arguments which might eſcape your attention under one form, may have their due weight under another.

Let a man loſe a leg or an arm, or an eye or an ear, he ſtill continues the ſame man, and holds his rank upon the liſt of beings as he did before; whatever can be ſeparated from him, he may look upon as a poſſeſſion, an inſtrument, or an organ of conveyance. But that alone, which remains after all imaginable ſeparation, is properly *himſelf*.

Beſides, our organs have their ſeparate offices, not *interchangeable* with one another. The *eye* which *ſees* cannot *hear*, and the *ear* which *hears* can never *ſee*; but theſe being *numerically* diſtinct, if they were the perceptive ſubſtance, it would follow, that what ſees is a different thing or ſubſtance from that which hears. Therefore, they can only be channels of conveyance to ſome one individual thing; for no man can doubt that it is the ſame himſelf which ſees, and hears, and receives all the perceptions; and we cannot conceive this ſelf diviſible, becauſe what might be taken away upon diviſion, would not be him, for he cannot be parted from himſelf.

Compound bodies conſiſt of parts, having the ſame nature and primary proportion with themſelves; nor is it conceivable, that any aſſortment of unſolid or immoveable parts ſhould form a ſolid and moveable body. For if compoſition prevailed in mind, every *ſelf* muſt contain a number of little ſelves, every mind many little minds, and every ſentient principle a multitude of ſentient principles. But this is a propoſal that will not bear mentioning; for who would not be ſhocked to hear talk of a half or a quarter of a man's ſelf?

To avoid this abſurdity, ſome have aſſerted, that *ſelf*, *mind*, or a *perceptive* being, may be produced by a combination of *unperceptive* principles. Not to urge that in this caſe a creation may be effected by compounding, let us remark, that upon ſuch a combination, the parts conſidered ſimply, cannot have, nor are they pretended to have, any other properties than they poſſeſſed before; neither can they club to take their ſeveral ſhares of a perception; for perception has not parts without parts, and therefore cannot be received piece-meal; but the perceptivity reſides in the whole compound jointly.—Now it ſeems very hard to underſtand how a collection of diſtinct ſubſtances, for ſuch every compound muſt be, can perceive what is not perceived by each of them. I can conceive a whole camp to hear the evening gun, becauſe every man in the camp hears it; but I *cannot comprehend* how they can *all* hear a ſound that eſcapes every *ſingle* perſon; nor can I, for my life, diſtinguiſh between their all hearing it, and every one of them hearing it. I can no more comprehend how an imperfect whiſper, heard by twenty perſons, ſhall become an audible voice, than how they can all hear a ſound heard by none of them ſingly.

If the mind be a compound, then upon ſome of the parts being ſlipped away, and others ſubſtituted in their room, though it might ſtill remain a mind, it muſt be a different one from what it was before; and as Lucretius tells us, the mind grows and decays with the body, every man would have a different ſelf in his childhood, his maturity, and his old age!!

But it may be ſaid, mind is not ſo much a collection of particular atoms as a figure, or harmony, reſulting from the order wherein they lie, and may therefore continue the ſame, although ſome or all of the atoms be ſhifted. For if you place twelve ſhillings in a circle, change your ſhillings as often as you pleaſe, you do not alter the figure, which ſtill remains a circle. But what then becomes of our own exiſtence? For form has none, but is only a modification, or particular manner of exiſtence in body; and harmony has none, being nothing more than the concordance, or mutual congruity of ſounds, as perceived by mind.

I cannot conceive it poſſible, that perceptivity ſhould be annexed to a ſyſtem, by which muſt be underſtood a compoſition of matter: it muſt as diſtinct from each other as the particles; and if indefinitely diviſible, there is ſuch a confuſion of perceptions as is too abſurd for any thing but a jeſt.

But if matter be reducible to atoms, and every atom ſuppoſed to perceive, I would aſk, how atoms can be organized, ſo as to hear, ſee, ſmell, &c. And if organization be neceſſary to perception in matter, either ſuch perception ariſes entirely new on the organization, or the organization only gives a liberty of action to the perception that was prior and diſtinctly latent in every part.

But, if on the former ſuppoſition, ſuch perception be ſolely produced by the organization or modification, you muſt remember, that organization and modification, however exquiſite or mechanical, are ſtill no other than a mode of form or figure, the moſt extraneous and incidental of any property of matter; whereas perception is the moſt ſimple and abſolute of any thing we know, and by which alone we know all that we do know. Such an hypotheſis, therefore, carries in itſelf the moſt palpable contradiction and confutation, as it makes what is ſimple, abſolute, and invariable, to be produced by what is compound, precarious, and changeable.

But if it be alledged, that by the organization the parts become ſo loving and neighbourly, as by ſharing the perception of each other, to make one amicable union of the whole, each part muſt ſtill retain it's proper right to it's portion of perception; and if, upon any accident, a member of the ſyſtem be lopped off, a piece of ſuch united perception being gone, we have only a piece of perception. And thus perception, the moſt ſimpl of all units, muſt be daily and hourly divided b the perpetual flux of matter.

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Thus, if the intelligence within us was corporeal, what one part knows would be unknown to the other; we could not compare nor unite our ideas, ſo as to make propoſitions, nor theſe propoſitions, ſo as to form arguments, nor theſe arguments, ſo as to form one continued diſcourſe. All the operations of comparing, uniting, and compounding our ideas, ſuppoſe *one individual, indiviſible, ſelf-conſcious, ſpiritual being*. Moreover, we hear, ſee, taſte, touch, and ſmell, by five different organs; and theſe ſenſations are as different as the organs themſelves; yet they are all united in the ſame ſubſtance which compares them, judges of them, and diſtinguiſhes between them. The change of form, bulk, and place in organized or unorganized bodies, does not alter the intimate eſſence of things, and therefore cannot add to them a new and diſſimilar property. Intelligence is a perfection, non-intelligence a defect; ſo that it is abſolutely impoſſible that what is unintelligent and inſenſible before organization, can become intelligent and ſelf-conſcious by organization; becauſe organization does not alter the nature of things. A maſs of numberleſs ſubtil, inviſible, and unintelligent polygons, ſpheres, cylinders, pyramids, or any other ſmall ſolids, cannot become intelligent and ſelf-conſcious by organical ſtructure.

Thus the poet: Where can this ſoul then take it's birth? Not ſure from matter, from dull clods of earth, but from a living ſpirit lodg'd within, which governs all the bodily machine, juſt as the almighty univerſal ſoul directs and animates the whole.

Ceaſe then to wonder how th' immortal mind can live, when from the body quite disjoined; but rather wonder if ſhe e'er could die, ſo fram'd, ſo faſhion'd for eternity; ſelf-mov'd, nor form'd of parts together tyed, which time can diſſipate, and force divide; for beings of this make can never die, whoſe powers within themſelves, and their own eſſence lie.

Having thus refuted the gloomy tenets of materialiſm, let us finiſh this Lecture with a different theme; let the conſideration of the wonderful powers of the ſoul make us attempt a higher ſtrain, an hymn of praiſe to the LORD OUR SAVIOUR, *the joy of every ſoul, the deſire of all nations.* For if in the verdure of the fields, and the azure of the ſky, the unlettered ruſtic admire thy creative power, how blind muſt that man be, who, contemplating his living ſtructure, and his moral frame, diſcerns not thy forming hand! How various and complicated the machinery of the one, how extenſive and noble the powers of the other!

How ſublime are all the faculties of the mind, thoughts that wing infinity; apprehenſions that reach through eternity; a fancy that creates; an imagination that contains a univerſe; wiſhes that a world hath not wherewithal to ſatisfy; deſires that know neither end nor bound! It is endued by thee with divine prerogatives, inveſted with ſpiritual powers, and enabled to aſpire ardently after the felicities of heaven.

Even while man purſues happineſs here as his chief aim, thou bindeſt ſelf-love into the ſocial direction; thou infuſeſt the generous principle, which makes him feel for ſorrows not his own; thy divine hand formed the connecting tye, and by ſympathy linked man to man, that all might tend towards mutual aſſociation; thy wiſdom has erected within him a throne for virtue; but thou haſt not decked her with beauty only, but haſt thrown around her the awful effulgence of divine authority; and yet thou haſt left him a field open for free and generous action, in which, performing a glorious courſe, he may attain the high reward by thee allotted; thou entertaineſt him with all the glories of the material world, and enableſt him to penetrate into the receſſes of nature. It is thou that giveſt to all bodies their forms and their motions, to all ſpirits their reaſon and their virtues; it is from thee that every thing flows, it is in thee that every thing exiſts, it is by thee that every thing lives, and to thee alone ſhould all things be referred. We ſee thee exiſting in wiſdom and in benevolence both ſupreme. As ſpots in the ſun's bright orb, ſo in the univerſal plan ſcattered evils are loſt in the blaze of ſuperabundant goodneſs. Even by the reſearch of human reaſon, weak as it is, thoſe ſeeming evils continually diminiſh and fly away; and objects ſuppoſed ſuperfluous or noxious aſſume a beneficial aſpect. How much more to thine all-penetrating eye muſt all appear excellent and fair! It muſt be ſo, we cannot doubt; neither imperfection nor malice dwell with thee; thou appointeſt as ſalutary what we lament as painful. Even the follies and vices of men adminiſter to thy wiſe deſigns; and as at the beginning of days, thou ſaweſt, ſo thou ſeeſt, and pronounceſt ſtill, *that every thing that thou haſt made is good.*

Now we ſee through a glaſs darkly, and know but in part, but the time cometh *when we ſhall know even as we are known*. We ſhall then ſee things in that ſacred *uncreated* light, which permits no error, which admits of no obſcurity. Then, O ALMIGHTY GOD, all that thou art now doing, all that thou haſt done, will be found harmoniouſly beautiful, and divinely worthy of thee, it's great and ſacred LORD. Then will thy creation and government appear ſublimely wiſe to the purified eye of man; and what nōw bewilders and perplexes us, what cannot now be comprehended by us, will be ſeen in all it's *unerring rectitude*, will bla forth upon us in the clearneſs of it's holy ſple dor, and we ſhall join with angels and archange in declaring that heaven and earth are full of t glory. *

* Lord Kaims.—Comyns's Sermons,

LECTURE XXVI.

ON MECHANICS.

ONE of the firſt arts men had occaſion to practiſe was that of MECHANICS; it was therefore ſtudied in the earlieſt ages of the world. Poſſeſſing very little theory, what knowledge they acquired was more the reſult of experience than reaſoning, having neither any methods of working, nor inſtruments to work with, but what they muſt firſt invent; their progreſs was ſlow, their performances rude and imperfect.

We hear therefore of no conſiderable mechanical inventions for a long ſeries of ages; the *firſt* we find mentioned are in the book of *Geneſis*; there we find that ſhips were as old, even on the Mediterranean, as the days of Jacob. In the time of Saul, 1070 years before CHRIST, we find the Philiſtines bringing 30,000 chariots into the field; in 1030 before Chriſt, Ammon built tall and long ſhips with ſails, on the Red Sea and the Mediterranean; about 800 years before Chriſt, *Uzziah* made engines to be on the towers and on the bulwarks, to ſhoot arrows and great ſtones.

Corn-mills were of early invention, for in Deuteronomy we find it was not lawful for any man to pledge the nether or the upper mill-ſtone. In Jeremiah we read of the potter's wheel. The works of Archimedes, who lived about 200 years before Chriſt, would alone afford ſufficient matter for a volume; ſome of his diſcoveries appear ſo much above the reach of men, that many among the moderns have found it more eaſy to doubt their exiſtence than to imitate them. His name ſtill occupies the foremoſt ranks in the ſcience of mathematics. By mechanical knowledge, he alone, for three ſucceſſive years, ſupported the tottering towers of Syracuſe, and baffled the attempts of the Romans. Marcellus admired the ſuperior ſcience of Archimedes: he inſtructed the Romans to reſpect his ſafety, but the impatience of a ſoldier proved fatal to his life.

It is not eaſy at this diſtance of time to conceive the nature of their machines, or ſay how they reared their bulky towers 150 feet in height, and 60 in circumference, with a battering ram at the bottom ſufficient to beat down walls, with a drawbridge in the middle to be let down upon the wall of the attacked city; and at the top a body of men, who being placed above the beſieged, harraſſed them without danger.

It would be endleſs to enumerate the inſtances of their mechanical abilities. *Italy* is filled with monuments, and the ruins of monuments, which aid us in comprehending the reſources and genius of the ancient Romans. The ſtones which are laid upon the tops of the pyramids of Egypt, each of which are as large as a ſmall houſe, create even wonder in a modern mechanic, and teach him to reverence the ſuperior arts of antiquity.

"Ignorant of the numerous arts which depend on mechanical knowledge, man would exiſt as in a deſert, comfortleſs and unſocial, little ſuperior in enjoyment to the lion and the tyger, but much their inferior in ſtrength and ſafety." Aided by theſe the fields are cultivated, the wilderneſs becomes a garden, ſtrength is given to the fortreſs, and elegance to the palace; and man beholds himſelf far removed from thoſe animals, to whom, while in a ſtate of nature, he ſeems nearly allied.

But if the exertions of our mental powers in giving riſe to the arts are thus worthy of attention, it is ſurely proper to devote a few minutes in ſurveying the works of the DIVINE MECHANIC; here, which ſoever way you turn yourſelves, you will find the cleareſt footſteps of *omniſcience*.

Conſider then your CREATOR determining the preciſe number of ſubſtances; allotting properties and capacities, fitted to complete the grand deſign he had in view; forming the plan of a world which was to laſt for ages, with infinite varieties and ſucceſſive changes; where every particle muſt have it's appointed ſtation, every motion it's determinate direction and velocity; calculating at one glance all the combinations they will run into, the ſpecies of compound they will produce, their ſecondary operations, and mutual affections.

How ſtupendous muſt be that *wiſdom* which directed *infinite power*, and by which every thing was eſtabliſhed in *number*, *weight*, and *meaſure!* God knew the exact quantity of *inviſible force*, whereon fermentation, heat, exploſion, repulſion, and all the different kinds of attraction depend, which if it had been greater or leſs, would have been productive of infinite diſorder.

HE proportioned the elements, that none of them might either predominate or fall deficient, and contrived ſprings for mingling them together to concur in performing their ſeveral taſks; HE appointed the degree of influence in the ſun and moon, the inequalities of the earth, the riſe of exhalations, the varieties of ſoils, and other cauſes, which bring on the change of ſeaſons, the viciſſitudes of the weather, and various other diſpoſitions of the air, cauſing the earth to yield her increaſe in due ſeaſon, neither redundant nor wanting.

HE contrived the curious ſtructure of vegetables, the more admirable organization of animals, where every veſſel, gland, fibre, &c. performs it's appropriate office for the growth and preſervation of the whole. HE adapted the contexture

Change is therefore a neceſſary part of the definition of motion, it marks the genus of the thing defined. Motion is a change; but as there are many ſpecies of change, which of thoſe ſpecies is motion? The anſwer is, change of place. This marks the ſpecies, and diſtinguiſhes it from change of colour, figure, &c.

We cannot conceive of any actual motion, without combining together theſe three ideas, a *being* which moves, a *place* in which that being is, and the *change* of that place.

In motion is therefore ſuppoſed the *ſucceſſive* preſence of the thing moved in *different* parts of *ſpace;* therefore in our ideas of motion are involved the ideas of SPACE and TIME.

In treating of motion we have therefore to conſider, 1. The power or force which cauſes the motion. 2. The ſubſtance moved. 3. The ſpace paſſed over by the moving body. 4. The time or duration of the motion.

Space is the place of every exiſtence; it is diſtinguiſhed into abſolute and relative, or place and ſituation.

We do not perceive the *abſolute* place of any object. A perſon in the cabin of a ſhip does not think that the table changes it's *place*, if it remains faſtened to the ſame part of the deck.

We acquire our notion of time by means of a ſucceſſion of events.

Time is unbounded, continuous, unchangeable in the order of it's parts, homogeneous, and indefinitely diviſible.

There is ſo great an analogy between the affections of *time* and *ſpace*, that in moſt languages the ſame words are uſed to expreſs the affections of both. Hence it is that time may be expreſſed by lines, and meaſured by motion.

The boundaries between the ſucceſſive portion of time may be called *inſtants*, and very ſmall portions of it may be called *moments*.

Time may be diſtinguiſhed into abſolute and relative.

We perceive not the *abſolute* time of any event, but only it's *ſeaſon*, in relation to ſome other event.

All things are placed in *ſpace*, in the order of ſituation.

All events happen in *time*, in the order of ſucceſſion.

No motion is inſtantaneous.

In the paſſage of a moving point, from one part of ſpace to another, it paſſes through all the intermediate points of it's path.

Abſolute motion is the change of abſolute place.

Relative motion is the change of ſituation.

The abſolute and relative motions of a body may be different and even contrary.

The relative motions of bodies are the differences of their abſolute motion.

The real and abſolute motions of bodies are detected by means of obſervations made on their relative motions.

Motion is ſuſceptible of varieties in *quantity* and in *direction*.

Our ſenſes do not teſtify the abſolute motion or abſolute reſt of any body. When one body removes from another, this may be diſcerned by the ſenſes; but whether any body keeps the ſame part of abſolute ſpace, we do not perceive by our ſenſes. When one body ſeems to remove from another, we can infer with certainty that there is abſolute motion; but whether in the one or the other, or partly in both, is not diſcernible by ſenſe.

A man ſitting in a barge in motion is relatively at reſt, that is, with reſpect to the parts of the barge; but abſolutely in motion, being removed with the veſſel from one part of ſpace to another. On the contrary, the bargeman, who fixes a ſtaff in the ground, and gives motion to the barge by walking along the gun-wale, is abſolutely at reſt, for the ſtaff againſt which he leans is fixed; but relatively in motion, ſince with reſpect to the barge he walks from one end to the other. But if the earth be ſuppoſed in motion, the abſolute motion of the barge and it's contents will be compounded of it's relative motion together with the abſolute motion of the earth.

That affection of motion, by which we determine the quantity, is called VELOCITY. This term expreſſes the *rate* at which the time increaſes, compared with the rate at which the ſpace increaſes: or, *velocity* is that property of motion, by which the moving body runs through a certain ſpace in a determined time. We cannot gain a diſtinct idea of velocity, without combining together thoſe of ſpace and time: thus, in the caſe of a traveller, you know the quickneſs of his pace is meaſured by the ſpace he has gone over, and the time he has employed in going over it.

The DIRECTION of a motion is the poſition of the line along which it is performed. When the motion is curvilineal, the direction at any inſtant is the poſition of the *tangent* to that point of the curve where the moving point is ſituated.

The term *matter* is uſed to expreſs that ſubſtance of which all things that affect our corporeal ſenſes are compoſed.

Bodies are penetrated by other bodies without any removal of their parts, in conſequence of their poroſity; and therefore under the ſame viſible extenſion there may be different quantities of matter.

The *viſible extenſion* occupied by any body is called it's *volume* or *bulk.*

The *quantity of matter* in any body is eſtimated by it's *weight*, and this is often termed the *maſs.*

Thus a pound of gold and a pound of cork are of equal *maſs*, as they contain the ſame quantity of ponderating materials; yet they are of very unequal *volume.*

Denſity is a term, which in ſtrictneſs of language expreſſes the vicinity of particles, but in common language it expreſſes the quantity of gravitating matter contained in a certain magnitude or volume. Thus one body is ſaid to be more denſe than another when it contains more gravitating matter in the ſame ſpace; hence, as this quantity of matter in any body is proportional to it's weight, that body is the moſt denſe whoſe ſpecific gravity is greateſt.

Bodies of the ſame denſity contain equal quantities of matter in the ſame volume.

If the volume of two bodies is equal, their denſities are as their weight; if the denſity of one is double that of the other, it's weight is alſo double.

If two bodies have the ſame denſity, their weight are to each other as their volume; *ex. gr.* if the volume of A is double that of B, and their denſities are equal, A will be twice the weight of B.

Hence *the quantity of matter in bodies is ſaid to be in a compound ratio of their denſities and magnitudes.*

And the *denſity of bodies to be in a compound ratio of their maſs directly, and of their volume inverſely.*

All changes of motion are conſidered as indications and characteriſtics of active cauſes.

That which cauſes a change in the ſtate of motion pended by a loadſtone, or a ſtring. The known force is conceived to be oppoſed by another force, of which the exiſtence and agency are detected, and the kind and quantity by this means determined.

OF SIMPLE, REAL, UNIFORM, RECTILINEAL MOTION.

I conſider as ſimple that motion which is produced by one force acting inſtantaneouſly on the body, and cauſing it to deſcribe a right line with an uniform velocity, that is, deſcribing equal ſpaces in equal times.

It will be ſhewn hereafter that there is no ſingle motion but what may be conſidered as reſulting from various forces, tending jointly to carry the moving body to the ſame point; and reciprocally that there is no rectilinear uniform motion ſo compounded, but what it may be conſidered as produced by the ſimple action of one force.

Three circumſtances are to be conſidered in ſimple motion.

1. The velocity with which the body moves. 2. The force conſequent to it's motion. 3. The laws to which it is ſubject.

Here it may be proper to obſerve, (agreeable to a diſtinction of Ariſtotle) that there are two kinds of quantity, one which may be called *proper*, the other *improper*.

Proper quantity is that which is meaſured by it's own kind, without taking in any quantity of a different kind as a meaſure of it; thus a line is meaſured by known lines, as a foot, inches, &c.

Improper quantity is that which cannot be meaſured by it's own kind, but to which we aſſign a meaſure by the means of ſome proper quantity that is related to it; thus velocity of motion, when conſidered by itſelf, cannot be meaſured. We may perceive one body indeed to move faſter, another ſlower; but we can have no diſtinct idea of a proportion or *ratio* between their velocities, without taking in ſome other quantity of another kind to meaſure them by; in this caſe the meaſure is *time*. Having once aſſigned this meaſure, we can, and not till then, conceive one quantity to be double, triple, &c. that of another. The meaſure of an improper quantity ought always to be included in the definition thereof, for it is the giving it a meaſure that makes it a proper ſubject of mathematical reaſoning.

The velocity, as I have already obſerved, is that property of motion by which the moving body deſcribes a certain ſpace in a determined time.

A body moving has ſo much more velocity as it deſcribes a greater ſpace in a given time, or as it takes up leſs time in deſcribing the ſame ſpace; that is, the velocity of a moving body increaſes in proportion as the ſpace is augmented, or the time diminiſhed. Mathematicians expreſs this by ſaying, that in uniform motion, *the* VELOCITY *is directly as the ſpace, inverſely as the time*; and conſequently that the velocity is expreſſed by dividing the numbers, indicating the ſpace by thoſe that denote the time.

Thus, if one body (a) moves through a ſpace of 12 feet in 2 minutes, and another (b) through but 6 feet in the ſame time, the velocity of (a) is double that of (b); the velocity of (a) is expreſſed by 6, that of (b) by 2.

The velocities in *equal times* are therefore as the ſpaces deſcribed in theſe times.

But the velocity required to deſcribe *equal ſpaces* are reciprocally as the time employed.

The velocities of two bodies, which deſcribe ſpaces that are in the ſame ratio as the times, are reſpectively equal.

The velocities of two bodies deſcribing ſpaces which are reciprocally as the times, are to each other directly as the ſquares of the ſpaces, or reciprocally as the ſquares of the times.

The SPACES *deſcribed by a body are as the product of the velocity by the time, or in proportion of the times and velocities jointly.*

The *ſpaces* deſcribed with equal velocities are as the times.

The ſpaces deſcribed in equal times are as the velocities.

The *ſpaces* deſcribed in times reciprocally proportional to the velocities, are reſpectively equal.

The *ſpaces* deſcribed in times proportional to the velocities, are to each other as the ſquares of the velocities, or as the ſquares of the times.

The TIMES *are as the ſpaces directly, and as the velocities inverſely.*

The *times* therefore employed to deſcribe equal ſpaces are reciprocally as the velocities.

The *times* employed to deſcribe unequal ſpaces with equal velocities, are reſpectively as the ſpaces.

The *times* employed to paſs through ſpaces which are proportional to the velocities, are reſpectively equal.

The times employed in deſcribing ſpaces which are in the inverſe ratio of the velocities, are to each other reſpectively as the ſquares of the ſpaces, or reciprocally as the ſquares of the velocities.

VELOCITY is diſtinguiſhed into relative and abſolute.

Abſolute velocity is that which we have been juſt deſcribing, and is meaſured by dividing the ſpace by the time the moving body takes in deſcribing that ſpace. Thus, to know the velocity o a body that moves through 15 required ſpaces in 3 ſeconds, divide 15 by 3, and the quotient gives the velocity, that is, the ſpace deſcribed in each ſecond.

Relative velocity is that with which two or more bodies approach or ſeparate from each other.

1. To render the explanation of this ſubject more ſimple, I ſhall conſider, firſt, two bodies moving on the ſame line, *fig.* 1, *pl.* 1, *mechanics*;* for this purpoſe, let us ſuppoſe two bodies at the extremity of the line A B, one moving from A towards C, the other moving from B towards C, and with the velocities expreſſed by the lines A C, BC. Now it is evident, that they will approach each other with the ſum of theſe velocities, and conſequently that their relative velocity will be equal to the ſum of their abſolute velocity.

2. Again, ſuppoſe two bodies, *fig.* 2, *pl.* 1, placed at the middle of the line DC, the one moving from A to D, the other from B to C. It is here alſo plain, that they will ſeparate from each other with the velocities expreſſed by AD, BC, and conſequeutly that their relative velocities will be equal to the ſum of their abſolute velocities.

3. Let the bodies be placed on the line A C, *fig.* 3, *pl.* 1, and moving in the ſame direction, A moving from A to C, with a velocity denoted by AB; the body B moving alſo towards C, with a velocity expreſſed by B C. In this caſe, they will approach each other only with the exceſs of the velocity of A above B.

In the ſame manner, the relative velocity will be equal to the difference of the abſolute velocities, if at the end of the motion: and it is the ſame as to the velocity produced, whether the bodies be ſeparated or united; the ten forces ſtill acting upon them.

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* As ſince the firſt volume was printed off, I have come to a reſolution to bind the plates up ſeparately from the letter-preſs; the number of the plate will therefore refer to the ſubject treated of.

We muſt therefore take in the maſs, as well as the velocity, in order to judge of the force which animates a moving body; it's maſs, for the number of parts poſſeſſing a certain velocity, or given force; it's velocity, to know the intenſity of the force reſident in each of it's parts.

Thus, let the body *b*, weighing one pound, have ſix degrees of velocity, whilſt another body, *a*, of four pounds weight, has alſo ſix degrees of velocity; the body *a* may be conſidered as compoſed of four other bodies, each equal to *b*, and having the ſame velocity; conſequently the body *a* has four times the momentum, or quantity of motion, of *b*. Multiply the maſs *b*, equal 1, by it's velocity, and the product is 6; but multiplying the maſs *a*, of four pounds, by it's velocity 6, the product is 24; expreſſing the quantity of motion eſtimated by multiplying the quantity of matter by the velocity, and the *momentum*, or force, is conſidered *as in a ratio* compounded of the *quantity of matter and the velocity*.

As the quantity of motion in bodies is as the product of the maſs by the velocity, it follows, that the velocity is as the quotient of the motion divided by the maſs, and their maſs is as the motion divided by the velocity.

$$\begin{aligned} 4 \times 6 &= 24 \text{ the motion;} \\ \tfrac{24}{4} &= 6 \text{ the velocity;} \\ \tfrac{24}{6} &= 4 \text{ the maſs.} \end{aligned}$$

In computations relating to forces, motions, times, &c. the *proportions* of the quantities to each other are conſidered, and not the quantities themſelves.

ſelves. In ſuch computations therefore, when any two quantities are compared together, we may ſubſtitute any other two quantities, which have the ſame proportion to each other, as numbers, lines, &c.

1. It follows, from what has been ſaid on the quantity of motion, that if the velocity of a body increaſes whilſt it's maſs remains the ſame, it's force will be augmented as the velocity is increaſed; or if ſeveral bodies, of the ſame maſs, move with different degrees of velocity, their force will be as the velocities with which they move.

2. If ſeveral bodies are poſſeſſed of the ſame velocity, their forces will be as their maſſes; *i. e.* they will have as much more force as they have more maſs, being poſſeſſed of a greater number of parts animated with the ſame force.

3. That a force being given, it will produce leſs motion in a body, in proportion as that body contains a greater number of parts.

4. That the forces will be equal in two bodies, when the velocities are reciprocally as the maſſes; *i. e.* when the velocity of that which has the leaſt maſs, exceeds the velocity of that body with the greateſt maſs, as much as the maſs of this exceeds that of the former.

It follows from what has been ſaid, that a ſmall body may have as much *momentum*, or force, as a large one, provided their velocities are reciprocally proportional to their maſſes. This is one of the reaſons that, ſince the invention of gunpowder, the battering rams of the ancients have been diſuſed: for their machines were large and ponderous, not eaſily moved; and when moved, acting with only a ſmall velocity.

The effect of mechanical engines depends in a great degree upon this principle; for if a ſmall weight is to ballance a great one, we muſt con-only as unreaſonable, but as unneceſſary; there being no occaſion to conſider motion as the cauſe of it's own continuation; for motion is only an effect, and muſt, like all other effects, be referred to it's proper cauſe. The nature of motion will be more fully treated hereafter: I ſhall now only lay before you the ſentiments of ſome able men on the preſent law.

Dr. *Horſley*,* among others, confeſſes it cannot be defended, and "believes, with the author of the Ancient Metaphyſics, that ſome active principle is neceſſary for the continuance, as well as for the beginning, of motion. I know," ſays he, "that many *Newtonians* will not allow this: I believe they are miſled, as I myſelf have been formerly miſled, by the expreſſion *a ſtate of motion*. Motion is a change, a continuation of motion is a further change; a further change is a repeated effect, a repeated effect requires a repeating cauſe. State implies the contrary of change; and motion being change, a ſtate of motion is a contradiction in terms."

The property of bodies to perſevere in a ſtate of reſt or motion, which is announced by this law, is uſually termed their *vis inertiæ*, and ſometimes, in caſe of a moving body, their *vis inſita*, or *inherent* force. "Theſe terms, and the ideas conveyed by them," ſays Mr. Robinſon, profeſſor of philoſophy in Edinburgh, "are *inaccurate*, and ſhould be uſed only to expreſs the neceſſity we are under of employing force in order to produce a change in motion.

M. Prony, in his "Architecture Hydraulique," ſhews that theſe terms are equivocal, and only ſerve to perplex and confuſe the mind; that, ignorant of the nature of force, and the nature of motion,

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* Biſhop of St. David's.

tion, we ſhould confine ourſelves to the effects *alone*.

Mr. Berrington. "This *vis inertiæ*, or power of reſiſtance, is generally ſaid to be ſomething *paſſive;* ſomething which reſiſts action, but does not itſelf act. However, either to *reſiſt* is really to *act*, or elſe it is a word void of all meaning, and therefore ought to be exploded from a ſcience which is not to be amuſed with empty words.

LAW II. Every motion, or change of motion, in any body, muſt be proportional to, and in the direction of the force impreſſed.

This ſeems nothing more, than that any change ſhould be proportional to the cauſe producing ſuch change; and, conſidering motion as an effect, it will always be found, that a body receives it's motion in the ſame direction with the cauſe that acts upon it. If the cauſes of motions are various, and in different directions, the body acted upon muſt take an oblique or compound direction, reſolvable into two or more ſimple directions; and hence it will follow, that the cauſe of a curvilinear motion cannot poſſibly be ſimple, but muſt ariſe from the joint effect of different cauſes concurring at the ſame inſtant to act upon the body.

LAW III. Re-action is always aqual to action, and contrary thereto; or, in other words, the actions of two bodies on each other are always equal, and are exerted in oppoſite directions.

Action and *re-action* are *correlatives*; one cannot exiſt without the other: *reſiſtance*, or *re-action*, is a neceſſary condition to action: even action becomes re-action by a mere change of circumſtances. In other words, *a* acting on *b*, as it determines *b*, is ſaid to *act;* as it *reſiſts* the re-action of *b*, itſelf *re-acts:* and conſequently every body that acts, is at the ſame inſtant *active* and *re-active*.

If you preſs with a finger one ſcale of a b lance, to keep it in equilibrio with a weight in t other ſcale, you will find that the ſcale preſſed the finger acts againſt the finger with a for equal to that with which the other ſcale endeavo to deſcend. Thus, alſo, if a man in one boat, draws another boat, *b*, they will approach ea other with equal quantities of motion. If the co be cut in the middle, the part next *a* will fly ba towards *a*, and that part neareſt *b* will go to which would not happen if the cord was or drawn towards *a*.

When a horſe or horſes are drawing a boat barge againſt the ſtream up the river, the ro which connects them to the boat, draws the hor as much as they draw the boat. In other wor whatever motion the horſes communicate to t barge or boat, they loſe an equal quantity the ſelves: for ſuppoſe them to draw with a for equal to 100, and the force neceſſary to keep t cord tort be equal to 50, they will not be a to draw with any more than the remaining for 50; for the ſame force of muſcles and ſinews whi they exert in order to drag the boat, would, if th were freed from the incumbrance, enable them go much further than they can go, in the ſa time, while connected with the boat.

When a cannon is diſcharged, the rarifi powder acts equally on the ball and the breach the gun; for the rarified air, expanding itſelf ev way, will equally preſs the cannon backwards, a the ball forwards, communicating the ſame qua tity of motion to each, though the velocities very different. If the ball weighs 10 lb. and t cannon and carriage 10,000lb. the velocity of t ball will be 1000 times greater than that of t cannon, but the quantity of motion equal.

The re-action of the water on the oar oc ſions a boat to advance, and communicates to it as much motion as it received; the fiſhes perform by their tail and fins, and aquatic birds with their feet, what the waterman effects with his oar, the mutual action and re-action impelling them along.

Birds ſupport themſelves, and paſs through long tracts of air, notwithſtanding the weight of their bodies much exceeds that of an equal volume of the fluid in which they move. If their wings ſtrike and puſh the air towards the earth, it's re-action ſupports their bodies; if the air be puſhed towards the eaſt, it's re-action drives the bird towards the weſt. Birds which fly far, as the *ſwallow*, the *falcon*, &c. have generally ſmall bodies and large wings, proper to act on a large quantity of air; while thoſe whoſe flight is ſhort, and for a little time, have ſmaller wings, and ſtrike the air oftener than the others. If you compare the muſcles of a man's arm with thoſe in the wing of a bird, you will find that the moſt robuſt and agile man would never be able to move wings proportioned to the weight of his body, with a velocity capable of ſupporting him in the air.

Daniel Bernouilli propoſes a new way to navigate veſſels, founded on this principle of action and re-action. He requires a tube to be fixed to the ſtern of a veſſel, open at both ends, and kept conſtantly filled with water, by means of a pump. The water running out of the tube would act againſt that in which the veſſel lay; the re-action of this would puſh the veſſel forward without ſail or oar. Jacquier tried the experiment on a ſmall ſcale with ſucceſs.

OF COMPOUND MOTION.

By compound motion, I mean that whi produced by the ſimultaneous action of ſe powers acting in different directions.

The *compoſition is not in the motion,* but ir powers or forces by which it is produced.

General law of compound motion. Any l ſolicited to move by the ſimultaneous action of d rent forces acting upon it in different directions, take a mean direction between what each p tends to communicate to it, and will move a velocity proportionable to the force acting caciouſly: for as the body cannot move in directions than one at the ſame time, it muſt r in a direction reſulting from the combinatio the acting powers; and the intenſity of the ſ it receives, will be as the intenſity of the ſ ſubſiſting in each, independent of their o ſitions.

1. Thus, if two forces act at the ſame tir any body, and in the ſame direction, the body move with a velocity equal to the ſum of the city of the two forces acting upon it.

2. If the two forces are equal, and a exactly contrary directions, the body will not m as the equal and oppoſite forces of the acting deſtroy each other.

3. If the forces are unequal, but actin oppoſite directions, the body will move in th rection of the ſtrongeſt, with a velocity equal t difference of the velocities in the two given bo

PROPOSITION. *A body acted upon at the time, by two forces whoſe directions and inten are repreſented by the ſides of a parallelogram, deſcribe the diagonal in the ſame time it would*

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deſcribed either of the ſides, if it had been impelled by one force alone.

Let the body at *a*, *fig.* 4, *pl.* 1, be impelled by a force acting on it in the direction *a c*, which would cauſe it to move from *a* to *c*. At the ſame inſtant let it be impelled towards *b*, by a power that will carry it from *a* to *b*, in the ſame time, and acting in the direction *a b*. Complete the parallelogram, and draw the diagonal *a d*, and this line will repreſent the direction and diſtance the body will move in the ſame time, when acted upon by both conjointly. For let us ſuppoſe a trough, or tube, equal to *a b* in length, in which a ball, *a*, can move freely; and that in the ſame time that the ball is moving uniformly from *a* to *b*, the tube is alſo moved uniformly from *a* to *c*, but ſo as to be always parallel to *a b*, and with it's extremities to deſcribe the lines *a c*, *b d*. But the ball has moved from *a* to *b* in the tube, in the ſame time that the tube has deſcended to *c d*. Hence it is evident, that when the tube *a b* coincides with the line *c d*, the ball will be at the extremity *d* of that line, and that it is arrived in the ſame time it would have deſcribed either ſide. It is obvious, that it has alſo deſcribed the diagonal; for by aſſuming ſmaller forces, and forming the parallelograms *a e f g*, *a h i k*, &c. it will be found at every interval in the diagonal of the parallelogram. It's motion is alſo uniform, being left immediately to itſelf after the ſimultaneous action of the two forces. The *compoſition of motion*, and the *doctrine of projectiles*, depend on this propoſition.

The motions along *a b*, *a c*, may be called the *ſimple* or *conſtituent* motions; the motion along *a d*, is called the *compound*, or the *reſulting* motion.

When a body is kept at reſt by three forces, they

will

will be as the three ſides of a triangle parallel to the directions in which they act.

For they are repreſented by the diagonal and two ſides of the parallelogram forming a triangle, two of whoſe ſides lie in the direction of two of the forces, and the ſide parallel to the third force; and if the lines be drawn parallel to theſe directions, they will form a ſimilar triangle, and therefore the proportion of the ſides will be the ſame.

It follows, therefore, that the three forces will be as the reſpective ſides of a triangle perpendicular to which they act, becauſe ſuch a triangle will be ſimilar to the other. The three forces muſt be all directed to the ſame point, otherwiſe they will give the body a rotatory motion.

The converſe of this propoſition is true. A body acted upon by three forces, proportional to the three ſides of a triangle parallel to which they act, will be at reſt.

I ſhall now illuſtrate this reaſoning by a pleaſing experiment. Here is (*fig.* 1, *pl.* 2, *mechanics*) a ſquare frame, the ſides of which are divided into equal parts, and ſtrings are ſtrained from ſide to ſide, through the equal diviſions, forming a number of ſmaller ſquares: a ſtring is alſo ſtretched from one corner, A, to the other, F, of the frame, to repreſent a diagonal of the ſquare.

At H is a fixed pin, to which one end of a ſilk ſtring is tied, paſſing over a pulley at C. A braſs weight, M, is ſuſpended at the other end of the ſtring. The pulley is guided by two ſtrait parallel wires, ſtretched between H and I, and may be drawn from H to I, by a ſtring which paſſes over another pulley, at I.

By drawing the ſtring I, the pullies are moved from H to I, the weight is raiſed from F, and the center thereof deſcribes the diagonal of the frame.

Now the weight is acted upon by two forces; one determining it to move from F to O, in the ſame time that the other moves it from O to A. By obeying both theſe forces, it deſcribed, as you ſaw, the diagonal line.

OF THE COMPOSITION AND RESOLUTION OF FORCES.

A particle of matter may be urged by different forces at once, and it acquires a motion in which they combine their influence.

As the motion which it thus acquires might have been produced by the action of a ſingle force, thoſe forces, by whoſe joint action this motion is really produced, are conceived to have compoſed the force which would alone have produced the ſame motion. This is called the *compoſition of forces*; and the ſingle force which would have produced the ſame motion, is called the *reſulting force*, the *compound*, or *equivalent force*.

For ſimilar reaſons, any motion may be conſidered as reſulting from the joint actions of two or more forces. This is called the *reſolution of forces*; and the forces which are conceived to have produced the motion, are called *ſimple*, or *conſtituent forces*.

Thus, as the lines *a b*, *a c*, *fig*. 4, *pl*. 1, repreſent the effects of the two forces, when acting ſeparately; and *a d* their effect, when acting conjointly; we may conſider *a b*, *a c*, *a d*, as repreſenting the forces themſelves: for we eſtimate force only by it's effects; and may therefore conſider the line *a d* as a *ſingle* force, which may either be divided into *two*, or conſidered as the *reſult of two* forces, repreſented by *a b*, *a c*.

Therefore, in general, any body moving with a force repreſented by the diagonal of a parallelogram, may be conſidered as compounded of the forces repreſented by the ſides; for the motion will be the ſame as if it had been impelled by two forces proportionable to thoſe ſides; and as upon the diagonal an infinite number of parallelograms may be conſtructed, any ſingle force may be conſidered as *compounded* of more *forces*, and thus *reſolved* into numberleſs pairs of forces, acting in the direction of the ſides of thoſe parallelograms, and proportional thereto.

The practice of reducing compound forces to ſimple, and that of finding two of more forces equivalent to one, is alſo called THE COMPOSITION AND RESOLUTION OF FORCES.

As the two ſides, *a b*, *b d*, of the triangle *a b d*, *fig.* 4, *pl.* 1, are greater than *a d*, it is plain that the ſum of the two forces, acting ſucceſſively, is *greater* than the reſult from both, when acting together in different directions; therefore, when we ſubſtitute the force *a d*, for the two forces a b, d d, it is not becauſe it is equal to the other two, but becauſe it produces the ſame effect as they do, when acting in the given directions.

The compoſing forces and their effect are neceſſarily in the ſame plane, for the diagonal is always in the plane of it's parallelogram.

As a body ſubjected to the action of two ſimultaneous forces, neceſſarily deſcribes the diagonal of a parallelogram, whoſe adjacent ſides repreſent the direction and intenſities of theſe powers, while the diagonal repreſents the action of theſe two powers on the moving bodies; you may readily find the line a body will deſcribe, when you know the direction and intenſity of the forces by which it is actuated.

It is eaſy to determine by theſe principles not only the effect of *two* forces acting at the ſame time upon any body, but alſo that of any number of forces. In order to do this, firſt find the effect of two forces, compare this firſt effect with another force, from this compariſon the ſecond effect will be diſcovered; this may be uſed inſtead of the three powers already examined, to compare with one of the remaining forces, and proceeding in this manner you will obtain the general and laſt reſult.

As the two forces P, *p*, *fig.* 5, *pl.* 1, are ſuppoſed ſuch, that acting ſeparately, P would have carried the body from G to D, while the other would have carried it from G to A, it is evident that as P is to p, ſo is G D to G A.

As G is a body acted on by the two forces P, p, and as the ſpaces G D, G A, are paſſed over in the ſame time by theſe forces, it follows that G D, G A, repreſents the reſpective velocities, as well as the ſpaces of the two forces P, p.

If with the directions P G, p G, you conſtruct the parallelogram P G p F, the diagonal G B prolonged towards F will be the diagonal F G of the ſmaller parallelogram; this diagonal will therefore repreſent a force capable of carrying G to B, in the ſame time that B would have carried it to D, or p to A.

The force repreſented by P G will have the ſame effect as the two forces P, *p*, acting at the ſame time on G, and *the ſingle force F G may be ſubſtituted for the united forces P G, p G*; and reciprocally for the ſingle force F G you may ſubſtitute any other two forces, as P G, *p G, provided they be ſuch that the ſpaces G D, G A, that each acting ſeparately would have cauſed the body G to have deſcribed, by the ſides of a parallelogram, of which the ſpace G B deſcribed in the ſame time by the force F G be the diagonal.*

From what has been ſaid you will find the following effects on the body C; from whence we may conclude, that the effect of powers is only produced by their relative forces, and in the direction of thoſe relative forces.

From hence then you perceive, that if a particle of matter is urged at once by two forces, which would ſingly produce motions in the ſame or in oppoſite directions, the motion which the particle will acquire, is the ſum or the difference of the motions which they would produce ſingly.

A particle urged by equal and oppoſite forces will continue in it's former ſtate; and thoſe forces which produce no change of motion by their joint actions, are to be conſidered as equal and oppoſite. Such forces are ſaid to be in *equilibrio*, to *ballance* and *deſtroy* each other, and the particle is ſaid to be in *equilibrio*; when two forces ballance each other, they are conſidered as equal and oppoſite.

Any number of forces acting on a particle of matter, will be ballanced by a force equal and oppoſite to their equivalents.

If any number of forces are in equilibrio, and are conſidered in parcels, the equivalent of theſe forces would be in equilibrio.

If a number of forces are in equilibrio, and are eſtimated in one direction, or reduced to that direction, the force would be in equilibrio.

Problem. *Three forces concurring in a point with directions that are not in the ſame plane, to find the direction and expreſſion of one force equivalent thereto.* In *fig.* 9, *pl.* 1, let p C, P C, Q C, be the three given forces acting at the ſame time upon C, but ſituated in different planes.

Now it is clear, 1, that as two lines which meet are in the ſame plane, by drawing P D parallel to p C, and P D parallel to P C, you will form a parallelogram p D P C, in the plane of which the forces P C, p c exert their action. In the ſame manner we obtain the parallelogram C P A Q, for the plane in which P C, Q C exert their forces, and the parallelogram C Q E p for the forces Q C p C, ſo that by drawing E B parallel to p D, and D B parallel to p E, and joining A B, a parallelopiped is formed.

2. The forces P C, Q C may be reduced to one A C, which is in one of the two diagonal planes of the parallelopiped; and laſtly, the forces A C, p c are repreſented by the length and poſition of B c, which is a diagonal of the parallelopiped.

The ſame mode will anſwer for a greater number of forces acting in different planes on the ſame body.

The whole theory of the compoſition and reſolution of forces may be deduced from the following principle: *two forces acting at the ſame time on a body, in directions which are oblique to each other, do not move the body by that part of their force, which, on account of their obliquity, is oppoſite and contrary, but by what remains after the oppoſite forces are deducted.*

If ever ſo many forces acting againſt one another are kept in equilibrio by theſe actions, they may all be reduced to two equal and oppoſite forces.

For any two forces may, by compoſition, be reduced to one force acting in the ſame plane; and this laſt force and any other may likewiſe be reduced to one force acting in the plane of theſe; and ſo on, till they all be reduced at laſt to the action of two equal and oppoſite forces.

From the general tenor of what has been explained, I hope you have perceived, that, ſtrictly ſpeaking, there is no ſuch thing in the abſtract as an oblique force, or a force producing a motion in *a ſingle body* not in the direction of that force. The motion produced in every body is ſuppoſed to be in forces *can be laſting*, unleſs thoſe forces are perpetually renewed.

With the ſame apparatus you may perform a variety of experiments, with three, four, or five forces acting at once.

To illuſtrate further the nature and application of this article, let A B, *fig.* 10, *pl.* 1, repreſent an artificial kite, kept up by the wind, blowing in the direction W C; by drawing the ſtring A I B I H, fixed at A and B, the kite will gain ſuch a poſition, that H I produced will paſs through the center of gravity at C.

Draw C O perpendicular to B A, and D O perpendicular to the horizon H O. Then O C is the direction of the force of the wind that acts againſt the kite; and the force by which it is kept up, is as the ſquare of the ſine of the angle A C W, or C O D. Now if D O repreſent the given weight of the kite, C O will be the force of the wind acting againſt it, and C D the force pulling at the ſtring. The tail, E F, which generally has a ſmall weight at E, keeps the head of the kite always towards the wind.

As the direction of the ſtring always paſſes through C, the angle, A C H, and conſequently H C O, will be the ſame at all altitudes, and the kite can never aſcend ſo high as to make the angle C H O equal to A C H. Hence it follows, that the ſmaller the angle H C O is made, the higher ſhe will riſe: the greater the wind, or the lighter the kite, the higher alſo it will riſe.

The wings of a bird are ſo conſtructed, that in ſtriking downwards they expand to their greateſt, and become almoſt two planes, being ſomewhat hollow on the under ſide. Theſe planes are not then horizontal, the back part, K, *fig.* 11, *pl.* 1, being higher than the fore part, D F G; but in moving the wings upward, to fetch a new ſtroke, they go with the edge, D, F, G, foremoſt, and the wings contract, and become hollow. Their bodies are ſpecifically lighter than that of men and beaſts; their bones and feathers extremely porous, hollow, and light; the muſcles which move the wing downwards are exceeding large, and have been eſtimated, in ſome inſtances, to be not leſs than a ſixth part of the weight of the whole body. When a bird is on the ground, and intends to fly, he takes a large leap, and ſtretches his wings right from the body, and ſtrikes them downwards with great force, by which they are put into an oblique poſition; and the reſiſtance of the air acting ſtrongly againſt them from the ſtroke, impels them and the bird in a direction perpendicular to their planes; which is in an oblique direction, partly upwards, and partly horizontally forward. That part of the force tending upwards is deſtroyed by the weight of the bird; the horizontal force ſerves to carry him forward. The ſtroke being over, he moves his wings; which being contracted, and turning their edges upwards, meet with very little reſiſtance from the air. When they are ſufficiently elevated, he takes a ſecond ſtroke downwards, and the impulſe of the air again moves him forwards; and ſo from one ſtroke to another, which are only as ſo many leaps taken in the air. When the bird wants to turn to the right or left, he ſtrikes ſtrongly with the oppoſite wing, which impels him to the contrary ſide. The tail acts like the rudder of a ſhip; except only that it moves them upwards or downwards, inſtead of ſideways. If the bird wants to riſe, he puts the tail in the poſition I H; if to fall, in the poſition I L: whilſt in an horizontal poſition, it keeps him ſteady. A bird can, by ſpreading his wings, continue to move horizontally for ſome time, without ſtriking the air, becauſe he has acquired a ſufficient velocity and his wings being

parallel

parallel to the horizon, meet with but a ſmall reſiſtance; and when he begins to fall, he can eaſily ſteer himſelf upwards by his tail, till the motion he had acquired is nearly ſpent, when he muſt renew it by two or three more ſtrokes with his wings. On alighting, he expands his wings and tail full againſt the air, that they may meet with all the reſiſtance poſſible. The center of gravity of a bird is rather behind the wings: to counterballance this, they thruſt out their head and neck in flying.

It is impoſſible, as already obſerved, for men to fly by the ſtrength of their arms. For their pectoral muſcles are vaſtly too weak: in a man, they are not one-ſixtieth part of the muſcles of the body; in a bird, they are more than all the others put together.

Some birds are ſaid to fly a thouſand yards in a minute.

A *fiſh* ſwims by the help of his fins and tail; and fiſhes are nearly of the ſame ſpecific gravity with water. The muſcular force of the tail is very great: their direct motion is obtained by moving the tail from one ſide to the other with a vibrating motion. When going to move it, the fiſh turns the end oblique to the water, and moves it through it in that poſition. The water re-acts obliquely againſt the tail, and moves him partly forward and partly laterally. The lateral motion is corrected by the next ſtroke the contrary way, while the progreſſive motion is continued. They exert a very great force with their tail. By the help of the tail they alſo turn on one ſide; ſtriking ſtrongly with it on that ſide, and keeping it bent, it acts like the rudder of a ſhip. The fins of a fiſh keep it upright, eſpecially the belly fins, which act like two feet: without theſe he would ſwim with his belly upwards, as the center of gravity lies near the back. By contracting or expanding the fins, they alſo aſſiſt him in aſcending and deſcending: by inclining his tail obliquely, and turning it a little from an erect poſition to one ſide, it helps him to riſe and fall. Fiſh ſwim but ſlow, and ſoon tire; yet ſome are ſaid to ſwim ſeventy or eighty yards in a minute.

Brutes ſwim naturally; for they are ſpecifically lighter than water, and require but a ſmall part of their head out for breathing. It is alſo eaſy to them; for they uſe their legs in ſwimming after the ſame manner as they do in walking.

Men do not ſwim naturally, though they are ſpecifically lighter than water; for their heads are very large, and require to be almoſt out of the water for breathing, and their way of ſtriking has no analogy to walking. Men attain the art of ſwimming by practice and induſtry. The art conſiſts in ſtriking the water alternately with the feet and hands; which, like oars, row him forward. When he ſtrikes with his hands, he neither keeps the palm parallel, nor perpendicular to the horizon, but inclined; and his hands ſtriking the water obliquely, the reſiſtance of the water moves him partly upward and partly forward. Whilſt his hands are ſtriking, he gradually draws up his feet; and when the ſtroke of his hands is over, he ſtrikes with his feet, by extending his legs, and puſhing the ſoles of his feet againſt the water; and while he ſtrikes with his legs, he brings about his arms for a new ſtroke, and ſo on alternately; keeping the body ſomewhat oblique, that he may more eaſily erect his head, and keep his mouth above water.

LECTURE XXVII.

Of Accelerated Motion.

THOUGH the moſt unlettered ruſtic is ſen that the fall of a ſtone is to be dreaded in portion to the height from whence it deſce that if it falls from a place a foot above his h it is not ſo likely to be fatal as if it fell from houſe-top; yet the law of acceleration, in fa bodies, was not diſcovered till the time of lileo: to inveſtigate the effect of gravity on bodies was reſerved for him, who was one of greateſt ornaments of the age in which he liv

Motion is ſaid to be accelerated, if it's vel continually increaſes; to be *uniformly acceler* if it's velocity increaſes equally in equal time

Motion is ſaid to be retarded, if it's vel continually decreaſes; and to be *uniformly reta* if it's velocity decreaſes equally in equal times

In our general notions of acceleration o tardation, we abſtract our attention from all rieties, and they are ſuppoſed uniform: that i ſuppoſe that the velocities increaſe or dimini the ſame rate with the times, or that the ch of velocity are proportioned to the times in w they are acquired.

Accelerations and retardations may be c dered as quantities, and are meaſured by changes of velocity, which are uniformly acq in the ſame or equal times; they are therefore portional to the changes of velocity directly to the time in which they are uniformly acquired, inverſely.

If the velocities do not change at the ſame rate with the time, the acceleration or retardation is not conſtant.

If you ſuppoſe a body to be put in motion by a ſingle impulſe, and moving uniformly, to receive a new impulſe in the ſame direction, it's velocity will be augmented, and it will go on with the augmented velocity. If at each inſtant of it's motion it receives a new impulſe, the velocity will be continually increaſing; and if this impulſe is always equal, and acts in equal times, the velocity will be uniformly accelerated.

The force, which at every inſtant gives this new impulſe to a body, is called the accelerating force.

For the ſame reaſon, if a body had at firſt a certain velocity, and loſes equal parts at each equal inſtant, by new impulſions acting in a direction exactly contrary to it's motion, it is ſaid to be uniformly retarded.

Every body left to itſelf deſcends with an accelerated motion, and a direction which tends to the center of the earth. The force cauſing this acceleration, and occaſioning this tendency, is called *gravity.* It is a force always preſent; and which, conſtantly acting on bodies, uniformly accelerates their motion.

All that we can obſerve in motion, is the ſpace deſcribed, and the time in which it is deſcribing. From obſervations on theſe, we infer the proportions of the changing forces. Uniformly accelerated or retarded motion is therefore the indication of an invariable or conſtant force. The changes, therefore, of velocity in any time, by a force varying according to any law, is the proper meaſure of the accumulated or whole action of the force during this time.

I ſhall now endeavour to explain the law of bodies falling with an accelerated motion by the force of gravity. The accelerating force or gravity decreaſes, as the ſquares of the diſtances increaſe; but as the greateſt diſtance from which we can obſerve the force of falling bodies, bears no proportion to that from the center of the earth, we may conſider gravity as acting without any decreaſe, or, rather, that it's force is the ſame from the beginning to the end of the fall.

The nature of all accelerating forces is to act continually on the moving body, and to be ſucceſſively impelling it by an infinity of ſmall ſtrokes. But the accelerating force being thus repeated as often as there are inſtants in the given time, is proportional to the product of the weight by the laſt acquired velocity.

As gravity acts uniformly on all bodies at an equal diſtance from the center of the earth, let us ſuppoſe the time of the deſcent to be divided into a number of equal parts, infinitely ſmall; the impreſſion of gravity will occaſion the body to deſcend towards the earth in the firſt ſmall inſtant. Now if you ſuppoſe gravity to ceaſe to act, the body will deſcend uniformly, in conſequence of it's firſt impreſſion, with an infinitely ſmall velocity; but, on the contrary, if at the ſecond inſtant, a new and equal impulſe is added to the former; it's velocity, in the ſecond inſtant, will double that of the firſt; in the third, by the continued impulſe, three times; four times in the fourth; and ſo on: for the impreſſion made in the preceding inſtants are not at all impaired by thoſe that follow, but are, if I may be allowed the expreſſion, heaped one upon another; conſequently, as the body is ſuppoſed to receive a new impreſſion every moment of it's fall, the velocity increaſes, as the moments, or time increaſes.

In the right-angled triangle C A B, *fig.* 12, *pl.* 1, which opens wider, by equal degrees, from the point A towards B C, the baſe of the triangle expreſſes *a motion uniformly accelerated.*

The leg A B expreſſes the time in which this acceleration happens, and this time is divided into four equal parts, or moments, as A 1, 1 2, 2 3, 3 B. The ſmall lines in the triangle A 1 k, repeated at equal intervals, and increaſing in length by equal degrees, denote equal accelerations of the velocity from the inſtant in which a body begins to fall, and the ſmall equal lines in the ſquare 1 m, denote an equal velocity during the time expreſſed by the ſide 1, 2.

Theſe things being kept in mind, if you attend to the diagram, it will open to you all the conſequences of theſe poſitions.

The line 1 k will repreſent the velocity acquired by a falling body *in the firſt moment of time;* 2 l, the velocity acquired at the end of the ſecond moment of time; and 3 o, the velocity at the end of the third; and ſo on.

If the body, during the ſecond moment of time, ſhould retain the velocity 1 k, which it had acquired at the end of the firſt, it will deſcribe the ſquare ſurface 1, 2 m k; for this ſurface is generated by a continual repetition, or motion, of the line 1 k, during 1 2; as the area of the triangle a 1 k is deſcribed by an uniformly increaſing velocity during the time A 1. But the area of the ſquare is manifeſtly double the area of the triangle; whence it appears, that a body moving on, during a ſecond moment, with the velocity acquired at the end of the firſt, will fall *twice as far* in the ſecond moment, as in the firſt: and the ſame will be univerſally true, that the velocity acquired at the end of any given time, will carry the body twice as far in the ſame time.

But if the velocity continues to increaſe uniformly during the ſecond moment, then the ſpace will be as the triangle 1 2 l k, *thrice* as large as the triangle A 1 k.

The *whole ſpace* deſcribed by the body in the two firſt moments, will be as the area A 2 l, which is equal to four times the area A 1 k; whence it follows, that the ſpace deſcribed by the body in it's fall, is as the *ſquare of the time* in which it falls; for here the time is 2, the ſquare thereof 4.

In the third moment, were the body to fall with the velocity 2 l during the time 2 3, the ſpace deſcribed will be as the rectangle under the time and velocity, that is, as the rectangular ſpace 2 3 n l, equal to four times A 1 k; but as the velocity is ſtill uniform, the ſpace will be as the area 2 3 o l, five times as great as A 1 k. And thus will the rectangle under the time and velocity be always *increaſed by units*.

As the triangle A 1 k, A 2 l, A 3 o, A B C, are all ſimilar, as A 2 is the double of A 1, 2 l will be the double of 1 k; and as A 2 expreſſes the *time*, and 2 l *the velocity*, where the time is double, the velocity is double, therefore the *velocity is as the time*; and ſo on of the reſt.

If the ſpaces deſcribed in each moment be conſidered *ſeparately*, the ſpace in the firſt moment will be as 1, in the ſecond as 3, in the third as 5, in the fourth as 7, and ſo on in an arithmetical progreſſion; the common difference being 2.

Thus I have ſhewn you from theory, and which I ſhall, in the courſe of this Lecture, illuſtrate by experiment,

1. That in bodies falling freely by their own gravity, the ſpaces deſcribed in falling from reſt, are as the ſquares of the times of falling.

2. That the ſpaces deſcribed by falling bodies, are as the ſquares of the velocities.

3. That therefore the ſpaces deſcribed by falling bodies, are in the compound ratio of the times and the velocities acquired by falling.

4. If a body falls through any ſpace, and moves afterwards with the velocity gained in falling, it will deſcribe twice that ſpace in the time of it's falling.

The motion of a body thrown directly upwards is continually retarded, in the ſame manner as the motion of a falling body is accelerated: for the action of gravity, in this caſe, continually acts contrary to the motion of the riſing body; whereas in that of falling bodies it conſpires with it.

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As the power of gravity communicates to the body in every equal moment equal velocities, ſo the velocity of a body thrown upwards, is equally retarded in equal times; for the ſame force of gravity, which generates motion in a falling body, deſtroys it in a riſing one. It follows, therefore, that in the ſame time and manner the ſame velocities are generated and deſtroyed in the ſame times. A body thrown upwards continues to aſcend till it has loſt all it's motion, when it will begin to deſcend, and the motion will be juſt as much accelerated as it was before retarded; it therefore aſcends during the time that a body in falling can acquire the velocity with which it was thrown up.

And the heights to which bodies projected directly upwards, with different velocities, can aſcend, are to one another as the ſquares of their firſt velocities.

Therefore bodies aſcending deſcribe ſpaces which follow the progreſſion of the odd numbers taken in a retrograde order.

To render this ſubject ſtill clearer, let us apply this theory to practice. But here I muſt firſt premiſe, that when a body falls freely by the force of gravity, it will deſcribe about 16 feet and an inch in one ſecond of time; but, for the ſake of round numbers, I ſhall ſuppoſe it to be 16 feet. This meaſure has been deduced from the *motion of pendulums*; between which and the rectilinear deſcent of heavy bodies there is ſo cloſe a connection, that neither of them can be thoroughly underſtood independent of the other. Now as a body falls through 16 feet in the firſt ſecond, it follows, that at the end of the ſecond moment it will have fallen 16 multiplied by 4, equal 64 feet; the ſpace being as the *ſquares of the times*, and the ſquare of 2 is 4. By the ſame rule, at the end of the third ſecond it will have fallen 144 feet, equal 16 multiplied by 9; at the end of the fourth, 256 feet, equal 16 multiplied by 16.

Hence, if the ſpace be given through which a body is to fall, you may collect the time wherein it will finiſh it's deſcent: for let the number of feet in ſuch a ſpace be divided by 16, and the quotient will expreſs the ſquare root of the time ſought, in ſeconds and parts of a ſecond.

Thus, if the ſpace be 144 feet, this divided by 16 gives 9, of which the ſquare root is 3. The converſe of this is equally true; for if the time be given, the ſpace through which the body hath deſcended may be found. If you deſire to learn the depth of a well, from the ſurface of the earth to the ſurface of the water, let a bullet of lead be dropped therein, and let us ſuppoſe it to ſtrike the water in five ſeconds: the ſquare of 5 is 25; which, being multiplied by 16, the product will be 400 feet for the depth of the well.

Again, were you to ſee a maſs of burning matter, or a large red-hot ſtone, ſhot upwards from the mouth of a volcano, and could obſerve accurately the whole time of it's flight in the air, riſing and falling, which we will ſuppoſe thirty ſeconds, you may thence diſcover the height to which it aroſe, for a projected body will both riſe and fall in the ſame time; therefore we are to take half the above-mentioned time, or fifteen ſeconds: now 15 multiplied by 15, and this by 16, give 3600 feet, or 1200 yards, which is not far from three quarters of a mile.

But you are to obſerve, that in the application of this theory two things are taken for granted, before we arrive at any one of theſe concluſions: firſt, that the theory is true in practice to a mathematical exactneſs, of which you will ſoon ſee the proofs; ſecondly, that the motion is without impediment, or in a medium that gives no reſiſtance: but this is falſe, as the bodies meet with great interruptions from the reſiſtance of the air. Upon this account, the well whereof we are finding the depth, will not be ſo deep as may be imagined by ſeveral feet; nor the ſtone projected from the volcano riſe ſo high as we have already concluded. The reſiſtance of the air is liable to ſo many variations, as to render the finding the abſolute quantity of it at any time, a problem ſo difficult and complicated, as hardly to admit of an adequate ſolution.

OF MR. ATWOOD'S APPARATUS FOR MAKING EXPERIMENTS *on the rectilinear motion of bodies which are acted on by conſtant forces.** The machine before you, *fig.* 13, *pl.* 1, is the contrivance of Mr. Atwood, and renders ſenſible to the eye and ear the laws of motion uniformly accelerated or retarded,

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* Atwood's Treatiſe on the Rectilinear Motion of Bodies.

tarded, as well as thoſe of uniform motion, and that without employing a ſpace more than five and a half feet, which renders it extremely convenient for a courſe of Lectures.

Mechanical experiments are of two kinds; the one relating to the quieſcence of bodies, and the other to their motion.

Among the former are included thoſe which demonſtrate, or rather *make evident to the ſenſes*, the equilibrium of the mechanic powers, and the correſponding proportions of the weights ſuſtained, to the forces which ſuſtain them, the properties of the center of gravity, the compoſition and reſolution of forces, &c.

By the latter, or thoſe on motion, are ſhewn the laws of colliſion, of acceleration, and the various effects of forces which communicate motion to bodies.

Of mechanical experiments it may be proper to obſerve to you, that thoſe wherein an equilibrium is formed, will frequently *appear coincident* with the theory, *although conſiderable errors* are committed in their conſtruction. This ariſes from the effects of friction, tenacity, and other cauſes. The caſe is different in experiments concerning the motions of bodies; in which, whatever care be taken to render the proportion of the forces, and the weights moved, ſuch as is required by the theory; yet the interference of friction, which renders the former apparently more perfect than they really are, cauſes theſe to differ from the theory.

If the experiments are only deſigned to aſſiſt the imagination, by ſubſtituting ſenſible objects inſtead of abſtract and ideal quantities, an apparent agreement between the theory and experiment may be ſufficient to anſwer this purpoſe, although it may be produced from an erroneous conſtruction: ſuch experiments cannot, however, impreſs the

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mind with that ſatisfactory conviction that ariſes from experiments accurately made.

Dr. Deſaguliers tried the effect of falling bodies, by letting a leaden ball fall from the inner cupola of St. Paul's church, whoſe altitude from the ground is 272 feet. The ball deſcended through this ſpace in four ſeconds and a half; in which time, from theory, it ſhould have deſcended through 325,6 feet, which makes a difference of about one-fifth of the actual deſcent between the experiment and the theory. Dr. Deſaguliers ſhews, in his fifth lecture, that this difference aroſe principally from the reſiſtance of the air. To remedy the defects of theſe experiments, Mr. Atwood contrived his apparatus.

Of the maſs moved. In order to obtain an adequate idea of the laws that are obſerved in the communication of motion, and obſerve the effects of the moving force, the interference of all other force ſhould be prevented. The bodies impelled ſhould be conceived to exiſt in free ſpace, and be void of gravity or weight; ſo that to a given ſubſtance various degrees of force may be applied. This indeed cannot be effected in bodies falling freely near the earth's ſurface: we cannot abſtract the natural gravity, or weight, from any ſubſtance whatſoever; for the ſame ſubſtance is always impelled by the ſame force of gravity, which admits not of increaſe or diminution.

Yet this difficulty may be obviated by ballancing two equal weights, joined by a flexible line, which goes over a pulley. The axle of the pulley muſt reſt on wheels conſtructed for the purpoſe of diminiſhing friction.

The *motive force of gravity being deſtroyed by the contrary and equal action of the weights*, they will remain quieſcent till ſome force is applied to them. When any impulſe is communicated to them in a vertical direction, they will afterwards be obſerved to deſcribe equal ſpaces in equal times, or will move uniformly; and the velocity communicated will be preciſely the ſame, as if the ſame impulſe had been impreſſed on a quantity of matter equal to the two bodies exiſting in free ſpace without gravity, due allowance being made for the inertia of the wheels.

Thus, in this inſtrument, *fig*. 13, *pl*. 4, which is conſtructed to illuſtrate this ſubject experimentally, there are two equal weights, A, B, affixed to the extremities of a very fine and flexible ſilk line. This line is ſtretched over a wheel, *a b c d*, moveable round an horizontal axis. The two weights, A, B, being preciſely equal, and acting againſt each other, when the leaſt weight is ſuperadded to either, it will preponderate.

When the weights, A, B, are ſet in motion by the action of any weight, which I ſhall call *m*, the ſum of A added to B, added to *m*, would conſtitute the whole maſs moved; but then there is to be added the inertia of the materials which muſt neceſſarily be uſed in the communication of motion. Theſe materials are, 1. The large wheel, *a b c d*. 2. The four friction wheels, on which the axle of the wheel *a b c d* reſts: theſe wheels are uſed to prevent the loſs of motion which would be occaſioned by the friction of the axle, if it revolved on an immoveable ſurface. 3. The weight of the line: but this is too inconſiderable to have any effect.

Of the reſiſtance from the inertia of the pullies. If the whole maſs of the wheels were accumulated in the circumference of the wheel *a b c d*, it's inertia would be truly eſtimated by the quantity of matter moved. If their figure was regular, and the denſity diſtributed uniformly in each, mathematicians would furniſh us with rules for finding a weight, which, being accumulated uniformly in the circumference,

ference, a b c d, would exert an inertia equal to that of the wheels. But as the figures are wholly irregular, recourſe muſt be had to experiment for the diſcovery of ſuch a weight.

For this purpoſe a weight of 30 grains was affixed to a ſilk line (which did not weigh ½ of a grain); this line being wound round the wheel, the weight of 30 grains, by deſcending from the reſt, communicated motion to the wheel; and, by many trials, was obſerved to deſcribe a ſpace of 38½ inches in three ſeconds. From theſe data we find the maſs equivalent to the inertia to be 2¾ oz. This is a maſs equivalent to the inertia of the wheel a b c d, and the friction wheels together.*

The reſiſtance to motion, therefore, ariſing from the wheel's inertion, will be the ſame as if it were abſolutely removed, and a maſs of 2¼ were accumulated in the circumference of the wheel a b c d.

This being premiſed, ſuſpend the pieces A B, by a ſilk line paſſing over the wheel a b c d, and make them ballance each other: now if I add any weight *m* to A, ſo that it ſhall deſcend, the exact quantity of matter moved will be aſcertained, for it will be A added to B, added to m, added to 2¾ oz.

In order to avoid troubleſome computations in adjuſting the quantities of matter moved, and the moving forces, ¼ oz. is aſſumed as a ſtandard weight of convenient magnitude, to which all others are referred; this weight is called m. Now the inertia of the wheel being $2\frac{1}{4}$ oz. will be denoted by 11 m; A and B, the pieces to which the different weights are applied, are each together with the hooks, by which they are ſuſpended equal $1\frac{1}{2}$ oz. or 6 m. We have a variety of different weights, ſome of which are equivalent to 4 m, others to 2 m, ſome equal m, and others to aliquot parts thereof.

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* Mr. Atwood proves, in his work,† that the following formula will give the required maſs $\frac{p \times t^2 d}{s} - p = x$, where p ſignifies the weight (30 gr.), t the time (3 ſeconds), d the ſpace deſcribed by a body in a ſecond (16 feet 1 inch, or 193 inches), s, the ſpace deſcribed by the body (385 inches), and x the inertia ſought.

That is in figures for the preſent caſe, $\frac{30 \times 3^2 \times 193}{385} - 30$ equal to 1323 grains, or 2¾ oz.

† Atwood on Rectilinear Motion, p. 226.

If then I apply 19 m to each of the pieces A, B, theſe, with thoſe pieces, will each be equal 25 m, ballancing themſelves, and the whole maſs will be 50 m, which being added to 11 m, the inertia of the wheels, the *whole maſs* will be 61 m; now add m to both A and B, and the whole maſs will be 63 m, perfectly in equilibrio and moveable by the leaſt weight, added to either (ſetting aſide the effect of friction), *in the ſame manner preciſely as if the ſame weight or force were applied to communicate motion to the maſs* 63 *m, exiſting in free ſpace and without gravity.*

Of the moving force. As the natural weight, or gravity of any given ſubſtance is conſtant, and the exact quantity eaſily eſtimated, we ſhall apply a weight as a moving force; thus, when the ſyſtem conſiſts of a maſs equal 63 m, I apply a weight m to A, and it communicates motion to the whole ſyſtem; the whole quantity of matter moved is 64 m; the moving force m, this gives us the force which *accelerates* the deſcent of A, being $\frac{m}{64}$ m or $\frac{1}{64}$ part of the accelerating force, by which the bodies deſcend freely towards the earth.

You ſee by this example, that the moving force may be altered without altering the maſs moved; for ſuppoſe the three weights m, two of which are placed on A and one on B, be removed, then A will ballance B.

Now place the weights 3 m on A, and the

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oving force will be 3 m, and the maſs moved 64 before, and the force which accelerates the deent of A equal $\frac{3m}{64m}$.

To make the moving force 2 m, remove the weights m, A and B will ballance one another, nd the whole weight will be 61 m; add $\frac{1}{2}$ m to A nd $\frac{1}{2}$ m to B, and the maſs moved will be 61 m; now place 2 m on A, and the maſs moved is 64 as before, whereof the force of acceleration is equal $\frac{1}{32}$ part of the acceleration of gravity.

Of the ſpace deſcribed. The body A deſcends, as you perceive, in a vertical line, along the ſcale which is about 64 inches long, and is graduated into inches and tenths: this ſcale is ſo adjuſted as to be vertical, and ſo placed that the deſcending weight may fall in the middle of the ſtage C D, fixed to receive it at the end of the deſcent; the beginning of the deſcent is eſtimated from o on the ſcale, when the bottom of A is level or even with o; the deſcent of A is terminated, when the bottom ſtrikes the ſtage; the ſituation or diſtance of the ſtage may be varied at pleaſure within the range of 64 inches.

Of the time of motion. The time of the motion is obſerved by the beats of this pendulum affixed to the pillar, and which vibrates ſeconds.

Many mechanical devices might be applied for letting the weight A begin it's deſcent at the inſtant of the beat of the pendulum; but it is ſimpler, and I think better, to let the bottom of the piece A, when even with o on the ſcale, reſt on a flat rod held in the hand horizontally, it's extremity being coincident with o; by attending to the beats of the pendulum, you may, with a little practice, remove the rod which ſupports the box, at the *inſtant* the pendulum beats, ſo that the deſcent of A ſhall commence at the ſame inſtant.

Of the velocity acquired. I have only now to ſhew you in what manner the velocity acquired by the deſcending weight A, at any given point of the ſpace through which it has deſcended, is made evident to the ſenſes.

The velocity of A's deſcent being continually accelerated, will be the ſame in no two points of the ſpace deſcribed; this is occaſioned by the *conſtant* action of the moving force: and ſince the velocity of A at any inſtant is meaſured by the ſpace which would be deſcribed by it moving uniformly for a given time, with the velocity it had acquired at that inſtant, this meaſure cannot be experimentally obtained, but by *removing* the force which cauſed the acceleration of the deſcending body.

To effect this, here are ſome weights or moving forces in form of bars or flat rods, to be laid on A; here is alſo a circular frame E F, to be fixed to the ſcale at any proper height, in ſuch manner that A will paſs centrally through it; when A *paſſes through* this frame, it *leaves the bar* by which it had been accelerated on the circular part of the frame. After the moving force *m* has been intercepted at the end of the given ſpace or time, there will be no force operating upon any part of the ſyſtem to accelerate or retard it's motion, and conſequently the inſtant *m* is removed, A will proceed uniformly with the velocity it had acquired that inſtant, and the velocity being uniform, will be meaſured by the ſpace deſcribed in any convenient number of ſeconds.

It may here be neceſſary to obſerve, that Mr. Atwood has clearly ſhewn, that the weight of the line can have no ſenſible effect on the experiments, for the inequality of the motion occaſioned by it does not amount to more than $\frac{1}{6.0312}$ of a ſecond, a quantity too ſmall to be diſtinguiſhed by the ſenſes.

The reſiſtance of the air does not affect the ſe experiments; for as the greateſt velocity communicated in theſe experiments does not exceed 26 inches in a ſecond, and the pieces A and B being only about 1¼ inch in diameter, the reſiſtance of the air can never increaſe the time of the deſcent in ſo great a proportion as 240 to 24, and will be therefore inſenſible in experiment.*

The effects of friction are almoſt wholly removed by the friction wheels. If the weight A and B be ballanced in perfect equilibrio, and the whole maſs conſiſts of 63 m, a weight of 2 grains, added to A or B, will communicate motion to the whole, which ſhews how inconſiderable the friction is; in ſome caſes, however, particularly in experiments on retarded motion, the effects of friction become ſenſible, but may be very readily and exactly removed by adding rather leſs than two grains to the deſcending weight; the weight ſhould be always leſs than what is ſufficient to put the whole in motion.

The ſpace which bodies deſcribe in one ſecond, by falling freely from reſt, is 193 inches; but in the enſuing experiments, the ſpace is taken at 192 inches (which will be productive of no error), in order to avoid fractions, which would render the uſe of the inſtrument leſs eaſy and intelligible.

Having now, I hope, ſufficiently explained the inſtrument, I ſhall proceed to experiments with it.

Let two equal weights be ſuſpended by a line, joining them, and going over a fixed pulley. *If any weight be added to them, it will preponderate, and in it's deſcent will deſcribe ſpaces which are as the ſquares of the times of falling from reſt.*

The equal weights are, in the preſent caſe, each equal 26 m, and the additional weight applied as a

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* Atwood on Rectilinear Motion, p. 314, 315.

force to communicate motion m. Then the n moved is m + 52 m + the inertia of the wheels 11 making in all 64 m. Now I ſhall ſhew you t the preponderating weight deſcending from qu cence during 1, 2, 3, ſeconds, deſcribes in the ſecond 3 inches; in the ſecond 3×4 or 12 inch in the third 3×9 or 27 inches; the ſpaces being ſpectively as the ſquares of the times of motion

To prove this, I affix the ſtage to 3 on graduated ſcale, bring the under ſurface of the pi A to coincide with 0 on the ſcale, and let it fal a beat of the pendulum, and you will find it ſt the ſtage when the pendulum beats again: it done ſo, having paſſed through three inches in ſecond. I ſhall now place the ſtage at twe inches, and the weight will ſtrike it exactly at ſecond ſecond; when placed at twenty-ſeven, ſtroke of the weight will coincide with the th ſecond.

I ſhall now ſubjoin a table of ſome expe ments of the ſame kind to be repeated by yo ſelves, which will rivet the theory more perfe in your mind, and render you readier in apply it to particular caſes. Let A hold 36 ¾ m, B, 36¼ The ſpaces deſcribed, &c. will be as in this tabl

Moving force.	Maſs moved.	Accelerating force.	Times of motion in ſeconds.	Spaces deſcrib from reſt eſtima in inches.
½ m	96 m	$\frac{1}{192}$	1	1
			2	4
			3	9
			4	16
			5	25
			6	36
			7	49
			8	64

If different forces are ſucceſſively applied to accelerate equal quantities of matter from quieſcence, the ſpaces deſcribed in any given time will be in the ſame proportion with the forces.

If any body, equal to 64 m, fall freely, or be acted upon by it's own natural weight, it will deſcribe 192 inches in the firſt ſecond of it's fall; but if the ſame maſs is impelled by only $\frac{1}{64}$ of it's accelerating force or 1 m, it will deſcribe only a 64th part of the former ſpace, that is, only three inches, a proportional effect.

To prove this, let A and B be each made equal 25 m, then will A and B be equal 50 m; to this add 11 for the inertia of the wheels, and we have 61 m: now put 2 m on A and 1 m on B, and the maſs moved will be 64 m, and the moving force 1 m.

Set the ſtage to three inches, and let the weight deſcend as before, and you will find it ſtrike the ſtage at the firſt ſecond.

If the ſame force impels different quantities of matter for any given time, the ſpaces deſcribed from reſt will be inverſely as the quantities of matter moved.

Let the force be *m*, and the maſs 64 m, and the ſpace deſcribed, during one ſecond, will be 3 inches.

Let the force be m, and the maſs 32 m, and the ſpace deſcribed in the ſame time will be ſix inches.

If the force be increaſed or diminiſhed in the ſame proportion with the maſs moved, the ſpaces deſcribed from reſt in the ſame time, will be equal.

Let m, 2 m, and 4 m, be the moving forces which impel the quantities of matter 32 m, 64 m, 128 m, reſpectively; then m will impel 32 m through ſix inches in a ſecond, and will impel 64 m, and 4 m will impel 128 m through the ſame ſpace in the ſame time.

From hence you may infer, that when different quantities of matter deſcribe equal ſpaces in equal times, being accelerated from quieſcence, the forces muſt be in the ſame proportion with the quantity of matter* moved.

If a body be moved from quieſcence during any given time, it will, at the end of that time, have acquired ſuch a velocity, as will, if continued uniform, carry it through double the ſpace which the body has already deſcribed to acquire that velocity.

Let the maſs moved be 64 m, the force m; but let m, which is applied to A as the moving force, be one of the flat rods. Place the circular frame ſo that A may, in deſcending, paſs through it, and it's height be ſuch, that the inſtant the lower ſurface of A arrives at twelve inches, the rod m may be intercepted by the ſurface of the circular frame, and thereby be prevented from the further acceleration of the ſyſtem. Let the other ſtage be ſet at thirty-ſix inches, that is, twenty-four from the circular frame.

Now, let the weight begin to deſcend from o on the ſcale at any beat of the pendulum; at the end of the ſecond beat, you will hear the rod ſtrike the circular frame, having deſcribed twelve inches with an uniformly accelerated motion; and at the fourth beat of the pendulum, it will ſtrike againſt the ſquare ſtage at thirty-ſix, having deſcribed twenty-four inches with an uniform motion.

If the ſame force acts on the ſame maſs for different times, one ſecond, two ſeconds, and three ſeconds, the velocities generated will then be ſix inches, 6×2 inches, and 6×3 inches in a ſecond reſpectively, being in the ſame proportion with the times wherein the given force acts.

Set the circular frame to three inches, and the ſtage to nine inches, let the maſs moved be 64 m, the moving force m; the weight A beginning it's deſcent at any beat of the pendulum, the rod will ſtrike the circular frame at the next beat: here the rod is removed, and A deſcribes the next ſix inches uniformly in one ſecond, ſtriking the ſtage at nine at the ſecond beat. By trying the apparatus in other inſtances, you will find the experiments coinciding with theory.

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* By this term I mean only the quantity of ponderable matter, for that there is other matter is evident from a thouſand experiments.

Theſe experiments ſhew, that if this force, by which bodies are accelerated, is the ſame, the velocities generated are in the ſame proportion as the times wherein the given force acts.

If a body is moved from reſt through the ſame ſpace by different forces, the velocities generated will be in a ſubduplicate ratio of the forces.

Let the maſs be 64 m, and the force m, you will find the velocity acquired in deſcribing twelve inches in two ſeconds, will, when the force is removed, carry it through twelve inches in one ſecond. Now let the maſs be 64 m, and the force 4 m, and you will find the body, in deſcribing twelve inches, will acquire a velocity of twenty-four inches, being in the ratio of 1 to 2, whereas the accelerating forces are in the ratio of 1 to 4.

If different quantities of matter be impelled through the ſame ſpace, and acquire the ſame velocity, the moving forces muſt be in the ſame ratio as the quantities of matter moved.

Let the quantities of matter be 64 m and 48 m, the ſpace twelve inches, the moving forces muſt be as 4 to 3. The following experiments will illuſtrate this truth.

Moving forces.	Quantities of matter.	Accelerating forces.	Spaces deſcribed in inches.	Velocities acquired in inches in a ſecond.
m	64 m	$\frac{1}{64}$	12	12
$\frac{3m}{2}$	96 m	$\frac{1}{64}$	12	12
$\frac{3m}{4}$	48 m	$\frac{1}{64}$	12	12

You may infer, from the two laſt ſets of experiments, that the moving forces, which impel bodies through the ſame ſpaces, are in the joint ratios of the quantities of matter moved, and the ſquare of the velocities generated.

If a given quantity of matter is impelled from reſt through different ſpaces by the action of the ſame force, the velocities generated will be in a ſubduplicate ratio of the ſpace deſcribed.

Let the quantity of matter be 64 m, the force m, the ſpaces 3 in. and 27 inches, the velocities will be in the ratio of 1 to 3; for it will deſcend in the firſt experiment through ſix inches in a ſecond; in the next you will find it go through 18 inches in a ſecond. Now the ſpaces are 3 and 27, or as 1 to 9; the velocities acquired as 6 to 18, or as 1 to 3.

Experiments on uniformly retarded motion. The laws obſerved during the motion of uniformly accelerated bodies, having been made evident to the ſenſes by the preceding experiments, I ſhall now proceed to illuſtrate the properties of uniformly retarded motion.

When a body is thrown perpendicularly upward from the earth's ſurface, it is continually reſiſted by a force which is equal to the body's weight; and the weights of all ſubſtances being proportional to the quantity of matter they contain, it follows, that the force which retards the perpendicular aſcent of any body, being meaſured by it's weight, divided by the aſcending maſs, is the ſame, being ſuch as deſtroys a velocity of 32$\frac{1}{4}$ feet in each ſecond of the body's motion. But in order to illuſtrate, by experiment, the general laws according to which bodies are retarded by the action of conſtant forces, ſuch methods ſhould be made uſe of as will enable us to apply different reſiſting forces to the ſame maſs of matter, and the ſame reſiſting force to different quantities of matter, both of which conditions will be ſatisfied by the inſtrument now before you.

A reſiſting force is to be underſtood as conveying preciſely the ſame idea as the term moving force; except ſo far as regards the directions in which thoſe forces act in reſpect to the body's motion, theſe directions being contrary to each other.

If equal quantities of matter are projected in free ſpace, with any given velocity, and are reſiſted by different but invariable forces, the ſpaces deſcribed before the whole motion is deſtroyed, will be inverſely as the reſiſting forces.

Let the maſs projected be 61 m, with a velocity of 18 inches in a ſecond, and let it be reſiſted ſucceſſively by the forces m, 2 m, 3 m; the ſpaces deſcribed before the motion of the body is deſtroyed will be $\frac{25.6}{1}$, $\frac{25.6}{2}$, $\frac{25.6}{3}$; theſe ſpaces being in the inverſe proportion of the reſiſting forces.

Make A equal $24\frac{1}{2}$ m, B equal $25\frac{1}{2}$; apply to the upper ſurface of A two rods, each equal m; then will the weight A preponderate and deſcend by the action of a moving force equal m, the whole maſs moved being equal 63 m. Set the circular frame to 26.44; then the weight A, by deſcribing from reſt the ſpace 26.44 inches, will acquire a velocity $= \sqrt{\frac{4 \times 193. \times 26.44}{63}}$, equal to 18 inches in a ſecond; and at that inſtant the two rods, each equal m, being removed, the weight will continue to deſcend with an uniformly retarded motion; which will be preciſely the ſame, as if a maſs of 61 m was projected with a velocity of 18 inches in a ſecond, in free ſpace, and a force of reſiſtance equal *m* were oppoſed to it's motion; wherefore A (with the other parts of the ſyſtem) will loſe it's motion gradually, and will deſcribe a ſpace equal to $\frac{18^2 \times 61}{4 \times 193} = 25.6$ inches before it's motion is entirely deſtroyed. You will therefore have to deſcend as low as 52 inches, before it begins to aſcend by the ſuperior weight B.

If any body, moving in free ſpace uniformly, is reſiſted by a conſtant force, for any given time leſs than that in which the whole motion would be deſtroyed, the ſpace deſcribed will be the difference between the ſpace which meaſures the initial velocity of motion multiplied into a number expreſſing the given time, and that ſpace which the body would deſcribe, if accelerated, during the given time, from quieſcence, by a force equal to that of reſiſtance.

Let a maſs 63½ m, be projected with a velocity of 11.877 inches in a ſecond; if it be reſiſted by a force equal to ½ m, it will deſcribe 21.95 inches in three ſeconds. To this end, make A equal 26 m, and B equal 26½ m, and apply a flat rod, 1½ m, to the upper ſurface of A; ſet the circular frame to 11.877 on the ſcale, then will A deſcend, the moving force being m, and the maſs moved equal 65 m. When it has deſcribed 11.877 inches, it will have acquired a velocity of 11.877 inches in a ſecond; and the rod being at that time intercepted, A will begin to deſcend with an uniformly retarded motion, and will ſtrike the ſquare ſtage ſet at 33.83, at the fifth beat of the pendulum, and thus deſcribe 21.95 inches in three ſeconds.

OF THE DESCENT OF BODIES ON INCLINED PLANES.

Having explained the deſcent of bodies falling freely by the force of gravity, it will be eaſy to eſtimate the force with which they will deſcend down an inclined plane; in which the direction of the fall is altered, but the abſolute force remains the ſame.

All bodies endeavour to fall by the ſhorteſt courſe, that is, perpendicular to the earth. When a body a body is with-held from obeying the impulſe of gravity, it is evident that it is prevented by ſome obſtacle which reſiſts it's natural tendency to deſcend. When bodies, therefore, fall down inclined planes, you muſt conſider them as obeying the uſual laws of gravity, as deſcending with an uniformly accelerated motion, but having the direction thereof changed, and the line of deſcent lengthened.

If the plane on which the body is placed be either perpendicular or parallel to the horizon, the direction of the line of deſcent is not changed: when the body is on a plane parallel to the horizon, it finds an invincible obſtacle to it's deſcent: when the plane is perpendicular to the horizon, it will fall freely, according to the laws already explained.

But when the *plane is inclined* to the horizon, it oppoſes in part the deſcent of the body towards the earth.

Thoſe bodies which deſcend on an inclined plane, have an abſolute and relative gravity.

Their abſolute gravity is the force with which they would deſcend perpendicularly to the earth's ſurface, if their fall were impeded by no obſtacle; their relative gravity is this ſame force diminiſhed by the reſiſtance of the plane.

The line A B, *fig.* 14, *pl.* 1, perpendicular to the horizon, is called the height of the plane; the oblique line, A D, is the length of the plane; the line B D, parallel to the horizon, is the baſe of the plane; and the angle A D B, that the plane makes with the horizon, is called the angle of inclination.

If a body falls freely from a ſtate of reſt the length of an inclined plane (A D), 1. *It's motion will be uniformly accelerated.* 2. *The velocity it acquires in it's deſcent, is to that which it would have acquired in the ſame time, falling freely and perpendicularly,*

pendicularly, as the height of the plane is to it's length.

Let C be a body placed on an inclined plane, the action of gravity would cauſe it to deſcend in the line C G, perpendicular to the earth: this line, therefore, repreſents the abſolute force of gravity on this body.

Reſolve the line C G into two forces; one, C F, perpendicular to the inclined plane, the other, C H, parallel to it. The line C F will repreſent that part of gravity which is deſtroyed by the inclined plane, or by which the body is prevented from falling; and the line C H, or F G, will repreſent the remaining force, or the relative gravity which acts on the body to make it deſcend.

The force, therefore, which acts on the body to make it deſcend, is to the abſolute force, or that which would cauſe it to fall freely and perpendicularly, as F G to C G; or the triangles D A B, C F G, being ſimilar, as A B to A D: and ſince in whatever place the body is ſituated, the triangle C F G is the ſame, it is plain that at every inſtant of the deſcent, the force F G, which cauſes the body to deſcend, is the ſame, or conſtant; and the motion produced is therefore uniformly accelerated, and will accord with the laws thereof.

As the motion of a body down an inclined plane is uniformly accelerated, in the ſame manner as the motion of a body falling freely, it follows, that at the end of any given time, the velocity acquired muſt be as the accelerating forces: but theſe are as the height of the plane to the length; and conſequently the velocities acquired at the end of any given time, muſt be in the ſame proportion.

It follows from hence, *that the force which cauſes the deſcent of a body on an inclined plane, is* *only the force of gravity diminiſhed in the ratio of the height of the inclined plane to it's length*; that the velocities acquired are as the times, and follow the progreſſion of the ordinary numbers 1, 2, 3, 4, 5; the ſpaces deſcribed from A, are as 1, 4, 9, 16, &c.; the ſpaces deſcribed in each interval, are as 1, 3, 5, 7; and, laſtly, the ſpace deſcribed in deſcending from A to D, is but half the ſpace the body would have deſcribed in the ſame time, moving uniformly with the velocity the body had acquired at D.

A little reflection, independent of geometry, will render the ſubject clear to you, and may perhaps be more agreeable. The plane oppoſes the perpendicular deſcent of any body, and conſequently diminiſhes it's abſolute gravity only in proportion to it's inclination: for if it were perpendicular to the horizon, it would not reſiſt at all the fall; but the more it is inclined, or the leſs the perpendicular height in proportion to it's length, the more the body is ſuſtained by the plane, and the leſs is it's relative gravity; conſequently the relative gravity of the body is to it's abſolute gravity, as the length of the plane to it's height.

If the angle of inclination becomes a right angle, the relative gravity becomes the ſame as the abſolute.

If there is no inclination, the relative gravity becomes 0, and the body has no tendency to move on the plane. If the angle of inclination is infinitely ſmall, the relative gravity will be alſo infinitely ſmall, increaſing with the angle of inclination.

If from the point B, fig. 14, pl. 1, *a perpendicular*, B K, *be drawn*, A K *will be the ſpace deſcribed by the body* C, *in the time it would have fallen freely from* A *to* B.

For, on account of the right angle at B, it is proved by geometry, that as A K is to A B, ſo is A B

A B to A D : that is, A K, the ſpace deſcribed by the body in deſcending from A to K, is to A B, the ſpace it would have deſcribed in falling freely in the ſame time from A to B; as A B, the velocity acquired by the body in deſcending from A to D, is to A D, the velocity it would have acquired in falling freely during this time.

But the velocity acquired by the body C, in deſcending from A to D, is to that which it would have acquired in falling freely during the ſame time as A to A D; therefore, while the body C falls from A to K, it would have fallen freely from A to B; or, in other words, A B and A K are the ſpaces that it deſcribes in the ſame time.

Coroll. If a body be, therefore, at any point K of an inclined plane, and the ſpace be required that it would have deſcribed in the ſame time from A, you may find it by letting fall a perpendicular from A D on A B, which will give the required point.

Coroll. A body takes up as much time in deſcribing the length of the chord A K, fig. 15, pl. 1 *of a circle, as to fall freely from a ſtate of reſt the length of the diameter* A B: for joining K B, the angle A K B will be a right angle, and the line A K will repreſent an inclined plane; and therefore, from the preceding article, the ſpaces A K, A B, ought to be deſcribed in the ſame time.

Therefore the times of deſcent on the chords of the ſame circle are equal; and if A, fig. 15, pl. 1, *is the point of contact common to ſeveral circles, bodies deſcending in the ſame time the length of the chords* A K, A D, A B, A E, *will deſcribe in equal times the parts* k K, d D, b B, e E.

Two bodies ſetting out at the ſame time from the ſame point A, and deſcending on planes A D, A M, *fig.* 14, *pl.* 1, differently inclined, *required* the ſpace of the body deſcending on A M. When the body deſcending on A D is at K, raiſe the perpendicula pendicular K B, and from the point where it meets the vertical A B, let fall the perpendicular A L, and L will be the point ſought.

The TIME *a body employs in deſcending an inclined plane, is to the time in which it would fall perpendicularly the ſame height, as the length of the plane to the height of it.* That is, the time a body employs to run from A to D, is as much longer than the time it would fall perpendicularly from A to B, as A D is longer than A B.

We have ſhewn that A K : A B :: A B : A D; from whence it follows, by geometry, that A K is to A D as the ſquare of the firſt to the ſquare of the ſecond.

You may illuſtrate this concluſion by numbers: 3 is to 6 as 6 to 12; and 3 is to 12, the third, as 9, the ſquare of the firſt, is to 36, the ſquare of the ſecond; for as 3 is contained four times in 12, ſo is 9 in 36. This being premiſed, we may find what proportion the time of deſcent, through a part of the plane A K, bears to the time of deſcent through the whole plane A D.

From the laws of uniformly accelerated motion, we know that the ſpaces deſcribed are as the ſquares of the times in which they are deſcribed; conſequently, as A K is to A D, ſo is the ſquare of the time in which A K is deſcribed, to the ſquare of the time in which A D is deſcribed: but the ſquare of A K is, to the ſquare of A B, as A K to A D; therefore the time of deſcent through A K, is to that through A D, as A K to A B; but A D is to A B, as A B to A D; conſequently, the time of the body in deſcending through A D, is to the time of the deſcent through A D, as A B, the height of the plane, to A D, the length of it: but ſince a body employs the ſame time in deſcending through A K as through A B, we conclude that the time of the perpendicular deſcent through A B, is to the time of the oblique deſcent through A D, as the height of the plane is to the length of it.

Hence we conclude, that the time employed to deſcend the length of any number of inclined planes of the ſame height, are to one another as the length of theſe planes; for A K is to A B, as the time employed to deſcend from A to D, is to that employed to deſcend from A to B. By the ſame reaſon, A M is to AB, as the time in deſcending from A to M is to the time ſpent in going from A to B; therefore the time employed to deſcend from A to D, is to that employed to deſcend from A to M, as A D to A M.

The velocity acquired by a body falling perpendicularly the height of an inclined plane, A B, fig. 14, pl. 1, *is equal to the velocity acquired at the end of the deſcent by a body moving down the inclined plane from* A *to* D.

For the accelerating force of a body falling freely from A to B, is to the accelerating force of a body moving along the plane A D, as A D to A B; but as A B is to A D, ſo is the time of the fall from A to B, to the time of the deſcent from A to D; ſo that the forces which accelerate the motions, are to one another reciprocally as the times that they continue to act; conſequently, at the end of thoſe times the velocities muſt be equal.

Or, in other words, the force of gravity, by which a body falls perpendicularly from A to B, is greater than the force by which it deſcends from A to D; but this laſt force acts ſo much longer as it is weaker, and therefore will in the end produce an equal effect, or velocity.

Conſequently the velocities acquired by bodies falling down inclined planes are equal, when the heights are equal.

If a body deſcends down ſeveral contiguous inclined

inclined planes, A B, B C, C D, fig. 17, pl. 1, *the velocity which it acquires in it's deſcent from* A *to* D, *is equal to the velocity acquired by the perpendicular fall from* A *to* D, *on a ſuppoſition that the body is not diſturbed by any reſiſtance it meets with at the angles* B *and* C.

Draw the horizontal lines H E and D F through the points A and D, and produce the line C B and D C as far as G and E.

By the corollary of the laſt propoſition, you know that the ſame velocity is acquired at B, by a body deſcending from A to B, as in deſcending from G to B; conſequently the ſame velocity is acquired in the point C, by a body deſcending from A through B to C, as in deſcending from G to C. But the velocity acquired in deſcending from G to C, is equal to the velocity acquired in deſcending from E to C; wherefore the velocity in the point D, acquired by the deſcent along the three planes A B, B C, and C D, is equal to the velocity acquired by the deſcent from E to D, which velocity is equal to the velocity acquired by the perpendicular fall from H to D.

It follows from hence, that as a body deſcends through an arch of a circle, or any other curve, it will have acquired, at the end of it's deſcent, a velocity equal to that it would have acquired by falling the perpendicular height of the arch.

For curves may be looked upon as compoſed of an infinite number of right lines.

If a body deſcends in a curve, and another deſcends perpendicularly from the ſame height, their velocities will be equal at all altitudes.

If a body, after it's deſcent in a curve, ſhould be directed upward with the velocity it had gained, it will aſcend to the ſame height from which it fell: for gravity acts with the ſame force, whether

the

Here is a triangular piece (*fig.* 22, *pl.* 1,) of braſs, ſupported by an axis paſſing through the center *c* of gravity; and you obſerve that it will reſt in any poſition I place it, whether the ſide be perpendicular, parallel, or inclined to the horizon.

All bodies by their *gravity* tend towards the center of the earth, and that by the ſhorteſt way; unleſs they are hindered by ſome obſtacle oppoſed to this tendency.

But *gravity* acts upon bodies as if their whole weight was collected in the center of gravity. It follows, therefore, that *this center will continually endeavour to deſcend towards the center of the earth*; and where all obſtacles are removed, does actually ſo deſcend.

But the effort of gravity is in lines perpendicular to the horizon; therefore a body will not reſt, except the center of gravity, and point of ſuſpenſion, are in the ſame vertical line.

A body ſuſpended freely by the center will not reſt, unleſs the center of gravity, and point of ſuſpenſion, are in the ſame vertical line.

In every other poſition, gravity is continually acting to make the body deſcend; but when the point of ſuſpenſion is in the ſame vertical line with, or directly oppoſed to the center of gravity, the action of the weight is deſtroyed, and an equilibrium takes place.

Reciprocally, whenever a body is in equilibrio, we may conclude it's center of gravity is ſupported in a vertical line.

This will be rendered more evident, by conſidering that gravity acts in a direction perpendicular to the horizon, and the whole weight of a body being collected into the center of gravity, that point will always endeavour *to deſcend in a vertical line*, and with a force equal to the body's weight:

for this reaſon, a vertical line paſſing through the body's center of gravity, is called *the line of direction.*

When the line of direction does not paſs through the center of ſuſpenſion, the body's weight may be reſolved into two forces; one of which impels the center of gravity directly from the center of ſuſpenſion, and is wholly counteracted, becauſe the center of ſuſpenſion is fixed; the other force, acting in a direction perpendicular to the former, and having no counterpoiſe, urges the center of gravity, in the direction of a tangent to that circle which that point deſcribes about the center of ſuſpenſion.

If a body be ſuſpended by a line from a fixed center, it will be at reſt only when the line coincides with a perpendicular to the horizon. An inſtrument of this kind is called a *plumb-line,* and is of very extenſive uſe, both in philoſophy and the mechanic arts. By means of this line, the vertical direction, and the horizontal plane, which is perpendicular to it, are preciſely determined. The ſame may be effected by the *ſpirit-level:* but the *plumb-line* has the advantage of requiring no adjuſtments; whereas the exactneſs of the level depends on the poſition of the points from which the level is ſuſpended, or of the baſe on which it reſts, in reſpect to the upper ſurface of the tube. It is beſides liable to ſome imperfections, from which the plumb-line is free.

Let us now illuſtrate the foregoing poſitions by experiment.

1. I ſuſpend this round board, *fig.* 2, *pl.* 2, on the points of the calipers A, in ſuch manner, that the center of gravity coincides with the center of motion; and in this inſtance, the body being both of a regular figure, and of an homogeneous ſubſtance, the center of gravity is exactly in the

and the line of direction paſſes within the baſe, it will ſtand; if it paſs without the baſe, it will fall.

While the line of direction paſſes through the baſe, the weight of the body keeps it down with force againſt the ſurface on which it reſts; but when the line of direction paſſes without the baſe, the center of gravity *loſes it's ſupport*, and the body falls until this center is ſuſtained.

Thus the inclining body A B C D, *fig.* 7, *pl.* 2, whoſe center of gravity is E, ſtands firmly on it's baſe C D I K, becauſe the line of direction E F falls within the baſe.

If a weight A B G H be laid upon the top of this body, the center of gravity of the body with the weight is raiſed to I; and as in this ſtate the center of gravity I is not ſupported, the whole tumbles down together.

From hence you may perceive how abſurd it is for people to riſe haſtily in a coach or boat, when it is likely to overſet, for by this means they raiſe the center of gravity ſo far as to endanger throwing it quite out of the baſe; if this be done, the vehicle will be effectually overſet, whereas by keeping as cloſe to the bottom as poſſible, they would bring the line of direction farther within the baſe, and probably prevent the carriage from being overſet.

The broader the baſe is, and the nearer the line of direction is to the center, the firmer will the body ſtand; on the contrary, the narrower the baſe, and the nearer the line of direction to the edge thereof, the more eaſily may the body be overthrown.

Upon this principle a body which would fall off the table of itſelf, will not fall off although you place a weight upon the part *which does not reſt upon the table*, provided you by that means throw the center of gravity of the whole under the table.

I place this piece of wood, *fig.* 1, *pl.* 4, upon the table with the part B from the table, and ſo that the point c may be over the edge thereof; it falls off becauſe the center of gravity is not ſupported; but by fixing the two wires D E, F G, with leaden heads into the board at B, it is ſupported, becauſe the center of gravity of all the three bodies is now ſupported by the table.

From hence you learn how to ballance a body reſting upon a point on it's under ſide; this is effected by ſuſpending a weight from each end, for by this means you bring the center of gravity *below* the point of ſuſpenſion, it brings itſelf to the loweſt point where it reſts; whereas before the weights were ſuſpended, the center of gravity was *above* the point of ſuſpenſion, and unleſs it had been exactly over it, which it is very difficult to accompliſh, it would deſcend, and the body muſt fall.

Various contrivances are executed that take their riſe from this principle, that the center of gravity always tends to the loweſt point poſſible. In France they make uſe of an *odometer*, or coach way-wizer, which is fixed between the ſpokes of one of the wheels; the moving power in this machine is a wheel loaded on one ſide with a weight, turning freely round with it's axis, the center of gravity being below the axis on which it turns. The center of gravity in every poſition keeps the loweſt point, ſo that the arbor and wheel turn once round for every revolution of the wheel; the arbor is properly connected with a train of wheels and pinions, ſo as to regiſter the revolutions of the coach-wheel.

Upon the ſame principle are alſo deduced the modes of ſuſpending the marine barometer, com-conſequently, if ſeveral bodies are united in a machine, or ſeveral combinations of bodies to be ſuſtained, no attention is to be paid to the center of gravity of the ſeveral parts which make the ſyſtem, but only to the center of the whole.

If a rod or beam be ſo conſtructed that the line drawn through the center of gravity and ſuſpenſion ſhall be perpendicular to any given line in the rod, (for example, that which paſſes along it's upper ſurface,) the rod hanging freely on it's axis of ſuſpenſion, will not be at reſt except when that given line is in an horizontal poſition.

Suſpend this triangular piece, *fig.* 22, *pl.* 1, by the center a, and when it has ceaſed vibrating, you will find the ſide which is perpendicular to a line drawn through the center of gravity and ſuſpenſion is in an horizontal poſition.

That this muſt happen is evident, becauſe the horizontal poſition, under the circumſtances here deſcribed, is the only poſition in which the line of direction paſſes through the line of ſuſpenſion.

Upon this principle the ballance by which the weights of bodies are compared is conſtructed.

OF THE SITUATION OF THE CENTER OF GRAVITY.

The center of gravity of any line is it's middle point.

The center of gravity in regular, uniform, and homogeneal ſolids, is at the center of it's figure.

For if from all the points on one ſide of the ſurface of this ſolid, lines are drawn through the center to the oppoſite ſide, theſe lines will be divided into two equal parts by the center; the two parts of each line are equal, and of equal weight, and conſequently the whole ſolid will be in equilibrio about that figure.

The center of gravity of the ſurface of a ſphere, or regular polyhedron, is the center of the figure; that of a priſm or cylinder is in the middle of the axis that paſſes through the center of gravity of their oppoſite baſes.

To find the center of gravity of the ſurface of a triangle A B C, *fig.* 19, *pl.* 1, biſect any two of it's ſides in D and E, draw lines from the oppoſite angles to the points, and the center of gravity will be in the interſection of the lines; for E A biſects all the lines drawn parallel to B C, which conſtitute the ſurface of the triangle, therefore it paſſes through the center of gravity of each line, and for the ſame reaſon D C paſſes through them alſo.

A ſimilar reaſon proves, that the center of gravity of a regular polygon, whoſe number of ſides is an odd number, is the ſame with the center of the figure.

The center of gravity of a triangle may be found by taking two-thirds of the line drawn from any one of it's angles to the middle of it's oppoſite ſide.

TO FIND THE CENTER OF GRAVITY OF A TRAPEZIUM.

Find the center of gravity of the two triangles formed by a diagonal, and join them by a ſtrait line; find and join alſo by a ſtrait line the center of gravity of two triangles formed by another diagonal; the interſection of theſe two lines will be the center required.

By the ſame means we may eaſily find the center of gravity of any polygon.

Divide the polygon into as many triangles leſs two as it has ſides, find the center of gravity of each triangle, and then conſidering theſe centers cede from each other with velocities reciprocally proportional to their maſſes, their center of gravity will remain at reſt.

If the bodies be made faſt upon the wire, and the center of gravity be ſuſtained on a pivot, it will remain at reſt though the bodies revolve round with the utmoſt velocity; and the bodies will deſcribe ſimilar circles about it and about each other, the one never overpowering the other.

If they be carried forward in any manner by any external force acting upon them in proportion to their maſſes, their center of gravity will go forward uniformly in a ſtrait line, and be moved juſt as if the two bodies were united into one at that center; and if they be projected, their center of gravity will move in the ſame curve as other projectiles, which is evident by the motion of an arrow, of chain ſhot, and of a ſtick thrown from the hand, the center of gravity of theſe bodies moving like a ſingle ball.

So alſo the earth and moon in their motion round the ſun, do neither of them deſcribe the real regular orbit, *but it is deſcribed by their common center of gravity in the ſame manner as if they were both united in that point*, or in the ſame manner the earth is ſuppoſed to do when theſe inequalities of motion are overlooked; and if their diſtances from the common center of gravity be reciprocally proportionable to their maſſes, their diſtances from each other may be greater or leſs in any proportion.

If to the two bodies A and B, *fig.* 9, *pl.* 2, there be added a third at D equal to one of the other, let A and B be reduced to their common center of gravity, and be conſidered as a body equal to both placed at C, then the common center of gravity of C and D will be found at K, as much nearer to C, as the maſs of the body or bodies at C exceeds that of the body at D. If the new body weighed but half as much as the others, it muſt be removed to d, ſo as to have the diſtance K d quadruple the diſtance K, C. Now if C D be a wire, and it be ſupported under K, the three bodies, whether D or d be uſed, will be thereby ſuſtained. In taking the center of gravity at K, we conſider the wire as a mathematical line without ſubſtance or weight.

If theſe three bodies, united to or acting upon one another proportionably to their maſſes, be carried round their common center of gravity, that point will be at reſt. Hence alſo in our ſyſtem, where the ſun and all the planets move round their common center of gravity, that center is at reſt in the middle of the ſyſtem. The ſun is on account of it's vaſt bulk, &c. compared with the other planets, conſidered in general as the center of the ſyſtem.

Though the center of gravity of a body, or of a ſyſtem of bodies, is often neither within the body itſelf, nor any of the combined bodies; yet it is to be conſidered, with reſpect to it's ſupport, deſcent, or motion, in any direction, as if it were ſo ſituated. Thus let us ſuppoſe A and b, *fig.* 24, *pl.* 1, to be at the diſtance A b from each other, and that A b is no longer a wire but a line repreſenting their diſtance, we ſhall then find their center of gravity at C without the bodies; and if inſtead of the wire C D, *fig.* 92, we ſuppoſe D joined to A and B by the wires A D, B D, the center of gravity K will be neither in theſe bodies nor the wire; ſo that to ſupport them you muſt ſuſtain ſome part of the wire, as G, which being made the center of motion, the center of gravity will be under it; or if we ſupport the point H, the bodies will be at reſt, becauſe the center of gravity is over H the center of motion.

In the ring A B E, *fig.* 10, *pl.* 2, the center gravity is in no part of the ring, but may be ſu ported by any other point, O or E. Thus the ce ter of gravity of the ring of Saturn is within t body of the planet; and though the common ce ter of gravity of the ſun, moon, and earth, is witl the body of the ſun, yet the common center gravity of the moon and earth is in neither of t bodies, but between them.

When any number of bodies move in rig lines with uniform motions, their common cent of gravity moves alſo in a right line with an u form motion; and the ſum of their motions, eſ mated in any given direction, is preciſely the ſa as if all the bodies in one maſs were carried with the direction and motion of their comm center of gravity.

For the ſum of the motions of the bodies eſ mated in any given direction is preſerved invari bly the ſame in their colliſions, without being a fected by their actions upon each that are eq and mutual, and have contrary directions; a conſequently their center of gravity is no wa affected by their colliſions on any ſuch actions, b perſeveres in a ſtate of reſt or uniform motion, any one body perſeveres in it's ſtate till influenc by ſome external circumſtance.

The name ſyſtem does not belong properly any unconnected aſſemblage of particles, but c only be applied with propriety to ſuch collecti of particles as are connected together by mecl nical forces. The varieties in ſuch connecti forces are innumerable, but we only conſider h the motions of ſuch ſyſtems whoſe particles connected by *mutual and equal forces*.

Equal and contrary motions communicated any ſyſtem of bodies will have no effect upon th center of gravity, for they would not diſturb

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ody equal to the ſum of them all placed in their enter of gravity.

The center of gravity of a ſyſtem of bodies ill not be diſturbed by their mutual attractions, the motions thus communicated are always equal d oppoſite ; hence the center of gravity of our ſtem is either at reſt, or moves on uniformly in a ait line. The latter is ſuppoſed by Dr. Herſchel be the caſe from the change which has been ſerved in the relative ſituation of ſome of the ed ſtars.

Hence alſo the center of gravity of the earth not affected by the motions on it's ſurface and wels: when a cannon ball, for inſtance, is thrown wards, the projecting force re-acting on the rth cauſes it to move in a contrary direction, but the motions are equal, the center of gravity re-ains the ſame.

The motions and actions of bodies upon each her in a ſpace that is carried uniformly forward, e the ſame as if that ſpace was at reſt ; and any wers or motions that act upon all the bodies ſo as produce equal velocities in them in the ſame or parallel right lines, have no effect on their mu-al actions or relative motions.

Thus the motions of bodies on board a ſhip at is carried ſteadily and uniformly forward, are rformed in the ſame manner as if the ſhip were reſt. When a fleet of ſhips is carried away by an iform current, their relative motions are no way ected by the current, but approach to or recede m each other as they would if no ſuch current iſted. The motion of the earth and air round axis has no effect on the action of bodies and nts on it's ſurface, only ſo far as it is not recti-eal and uniform.

In general, the actions of bodies on each other pend not upon their abſolute but relative motion, ried out firſt towards the right ſide, and then towards the left, at the ſame time that it goes forwards, which is the reaſon why thoſe who ſtraddle in their walk, as fat people commonly do, are obſerved to waddle: indeed every body waddles more or leſs, but they who walk pretty cloſe do it ſo little as not to be perceived.

Ducks, geeſe, and the greateſt part of water-fowl, whoſe legs are ſet wide aſunder for the convenience of ſwimming and turning quick in the water, have always a waddling motion upon land; but a cock, a ſtork, an oſtridge, and many other birds that are not web-footed, walk directly forwards without waddling, more eſpecially when they walk ſlow. Quadrupeds ſeldom or never waddle, becauſe they have commonly three feet upon the ground at a time. The ancients obſerving that horſes and other quadrupeds, in galloping, lift up their two fore feet and then their hind feet, as ſoon as the two fore feet are ſet down, imagined, that in walking, as well as pacing and trotting, an horſe has two feet off of the ground at one time; and accordingly in their ſtatues they have repreſented their horſes with two legs off the ground diagonally oppoſite: the modern ſtatuaries have fallen into the ſame error. Borelli has ſhewn, that this is an error, and inconſiſtent with the ſimplicity and wiſdom we obſerve in the works of nature; to his treatiſe, " De Motu animalium," I muſt refer you.

In ſkaiting, the line of direction paſſes through the foot on which the ſkaiter moves; and as he raiſes his foot from the ice, he ſcrapes it in a contrary direction to that in which he deſigns to move, and the reſiſtance of the ice upon it puſhes him forwards.

In jumping, the center of gravity riſes from the ground, and is carried forward at the ſame time. To render this plainer, I will explain it by a very ſimple inſtance: if you ſet one end of a bow ſtick on the ground, and with your hand bend down the other end, upon letting this end go the bow flies out at once, and jumps from the ground; for the elaſticity of the ſtick unbends it equally both ways, and as the action of one end is downwards and preſſes upon the ground, the re-action will be upwards, and the center of gravity will have a motion communicated to it in that direction, and will therefore continue to riſe, and the ſtick will by this means be carried off from the ground till it's weight puts a ſtop to it's farther aſcent, and makes it fall back again.

The force of the muſcles is that which in jumping ſupplies the place of elaſticity, for by bending the joints of the two heels, the two knees, and the two thighs, there are ſix bows bent; and if all theſe are ſuddenly ſtraitened by the force of the muſcles, the center of gravity of the body will have a motion upward communicated to it, and the body will by this means be made to riſe from the ground. If we are to jump directly upwards, we puſh the ground on which we ſtand directly downwards; but if we move obliquely, ſo as to riſe and to jump forwards at the ſame time, then we puſh the ground obliquely backwards with both feet together.

You may now conſider what it is that makes the difference between *walking* and *running:* if you imagine that theſe two modes of motion differ only in the degree of ſwiftneſs, and that as walking is a ſlow motion, ſo running is only a ſwifter motion of the ſame ſort, you are much miſtaken; for theſe two motions differ in ſort rather than in degree. Indeed they do not differ always in degree, for there are ſome who will walk faſter than others can run; we can walk quick and run ſlow; in a word, they are two entire different modes of motion. Walking is moving forward by ſteps, ſo as never to have both legs off the ground at the ſame time; running is moving forwards by jumps. Indeed in running we do not take our jumps with both legs cloſe together, but with one of them before the other; but I call it jumping, becauſe in throwing ourſelves forwards both legs are off the ground at once.

In *carrying a load* a man always leans ſo as to bring the center of gravity between his feet, and therefore leans the contrary way to the load. He naturally leans forward when he has a burthen on his back, for if he attempted to retain his uſual rectitude of figure, his center of gravity would be altered, and he muſt conſequently fall backward; for the ſame reaſons, when the burthen is on his breaſt, he counterballances the weight by altering his figure in the oppoſite poſition. In almoſt every inſtance of our motions we are obliged to make uſe of theſe ballancing arts to keep ourſelves upright; and it is uſually the ſtudy of a fine painter, to know how far the human figure may be bent without loſing it's center of gravity. De Vinci, one of the firſt painters after the revival of the art, has laid down rules upon this ſubject, which have been improved by ſucceeding painters.

LECTURE XXIX.

ON THE
MOTION OF PROJECTILES, PENDULUMS, &c.

OF THE MOTION OF PROJECTILES.*

IF a heavy body be projected directly upwards or downwards, it will be moved in a right line, but it's motion will be as we have ſhewn you, an uniformly accelerated or retarded motion, according as it is projected upwards or downwards; but if it be projected in an horizontal direction, or in any other direction that is oblique to the horizon, it will be carried in a curve line.

Galileo firſt inveſtigated the effects of *gravity* on falling bodies, and upon that foundation demonſtrated that all projectiles would move in a *parabola* in *a non-reſiſting medium*; and not taking the reſiſtance of the air into the account, he proved that a ball ſhot horizontally would, in it's flight, deſcribe half a parabola; and when the piece had an elevation above the horizon, the ball would deſcribe a whole parabola, ſuppoſing it to fall on the plane of the battery; and by the ſame method of reaſoning he ſhewed, that whatever the ranges of the projected body or the elevations of the piece were, the ball would ſtill trace that curve line, of a greater or leſſer amplitude, by the time it deſcended to the level of the place from whence it came.

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* Sir John Pringle's Diſcourſes.

Galileo confined his projections to the horizontal plane of the battery; but *Toricelli*, his diſciple, ſoon after carried the theory farther, by tracing the ſhot to it's *fall*, whether that place was above or below the plane; and ſtill found by *geometrical* deductions, that it flew in a parabola of a larger or ſmaller amplitude, according to the angle of elevation of the piece, and the ſtrength of the powder.

Galileo ſuſpected, that the reſiſtance of the air would divert the projectile from it's track, and propoſed ſome means for aſcertaining the inequalities ariſing from thence; yet thoſe who came after him, Newton and Huygens excepted, all aſſerted, that the reſiſtance of the air was ſo ſmall, that bodies moving through it would not ſenſibly deviate from the path they would deſcribe in *vacuo*, the velocity and direction of projection being the ſame.

Dr. Halley and other eminent mathematicians acquieſced in the juſtneſs and ſufficiency of the principles of gunnery invented by Galileo, and enlarged by Toricelli; nay, ſo far were theſe theoriſts from ſuſpecting any defect or fallacy in theſe principles, that they ſeemed rather to reproach the practical artilleriſts, for not profiting more by the inſtructions they had ſo liberally imparted to them.

Yet that either the theory of projectiles was defective, or the reſiſtance of the air ſuch as rendered it inapplicable to practice, was evident from numerous experiments. It has been found by experiment, that a muſquet ball, ¾ of an inch in diameter, fired with half it's weight of powder from a piece forty-five inches long, moves with a velocity of near 1700 feet in a ſecond; now if, according-ing to theory, this ball flew in the curve of a parabola, it's horizontal range at 45° would be found to be about 17 miles; but all practical writers aſſure us, this range is really ſhort of half a mile. One more inſtance: an iron bullet of 24 pounds weight, fired from a piece of the common dimenſions, with it's greateſt allotment of powder, hath a velocity of 1650 feet in a ſecond; now the horizontal range of this ſhot at 45°, computed according to the parabolic hypotheſis, will come out to be about ſixteen miles, which is five or ſix times it's real quantity; for practical writers all agree in making it leſs than three miles.

It is not only when projectiles move with theſe very great velocities, that their flight ſenſibly varies from the curve of a parabola; the ſame aberration often takes place in thoſe that move ſlow. In ſhort, ſays *M. de Reſſons*, a French officer of artillery, diſtinguiſhed by the number of ſieges at which he had ſerved, by his high military rank, and by his abilities in his profeſſion, "Although it be agreed that theory joined to practice does conſtitute the perfection of every art, experience had taught him that theory was of very little ſervice in the uſe of mortars; that practice had convinced him that there was no theory in the effects of gunpowder, for that having endeavoured, with the utmoſt care he was maſter of, to point a mortar agreeable to theory, yet he had never been able to eſtabliſh any ſolid foundation thereon."

Sir Iſaac Newton, in his Principia, has indeed particularly conſidered the reſiſtance of the air to projectiles moving with ſmall velocities; but as he had no opportunity of making experiments on thoſe which move with prodigious ſwiftneſs, he did not imagine that a difference in velocity would make ſuch a reſiſtance as it is now known to do. Sir Iſaac found, that in ſmall velocities the reſiſtance when the bullets are projected with very ſmall velocities; and conſequently that all application of the properties of that conic ſection to gunnery were ſo erroneous, as to be totally uſeleſs; thus giving *an inſtructive inſtance of the fallacy of the moſt ſpecious theories*, that do not proceed hand in hand with experiment.

Since Mr. Robins's time, many important and accurate experiments have been made on this ſubject by Dr. Hutton, Mr. Thompſon, and Lovel Edgworth, Eſq. but I ſhould exceed the bounds of theſe Lectures, were I to enter more minutely into their experiments, and muſt therefore refer you to thoſe authors who have treated particularly on theſe ſubjects. After what you have heard of the imperfection of this part of ſcience, it would be pedantry to dwell on the mathematical theory of projectiles, and thus endeavour to make you appear wiſe in your own eyes, or that of others, by a parade of demonſtration, and an uſeleſs diſplay of diagrams.

I ſhall therefore content myſelf with laying before you one or two of the principal propoſitions that are furniſhed by theory.

1. *If the force of gravity were conſtant, and acted in parallel lines, and* THERE WERE NO RESISTANCE FROM THE AIR, *bodies projected near the earth's ſurface would deſcribe a parabola.*

But the reſiſtance of the air is ſo great, that it will cauſe the body projected to deſcribe a path altogether different from a parabola; ſo that no practical concluſions can be drawn from this theory. This you may eaſily imagine, when you conſider that the reſiſtance of the air to a cannon-ball of twenty-four pounds weight, moving with it's initial velocity from a full charge of powder, is between five and ſix hundred pounds; which reſiſtance is above twenty times the ball's weight.

2. *If the velocity of projection be given, the horizontal range is the greateſt when the angle of elevation is 45°.*

This poſition alſo is only true on a ſuppoſition that the reſiſtance of the air had no effect; whereas it ſo influences military projectiles, that the greateſt range is at an angle much leſs than 45°.

In the art of gunnery, aberrations will take place from a variety of cauſes which can by no means be foreſeen or prevented. A difference in the denſity of the atmoſphere, in the dampneſs of the powder, or in the figure of the ſhot, will occaſion variations in the range of a bullet that cannot be reduced to any rules, and render the event of each ſhot very precarious. The reſiſtance of the atmoſphere, ſimply conſidered, is a problem that, notwithſtanding the labour of Mr. Robins, &c. has not been completely ſolved.

It is an objection that has been made to the mathematical philoſophy, and to which in many caſes it is moſt certainly liable, that it *conſiders the* RESISTANCE *of matter, more than it's capacity of giving motion to other matter.* Hence, if in any caſe matter acts both as a reſiſting and a moving power, and the mathematician overlooks it's effort towards motion, founding his demonſtration only upon it's property of reſiſting, theſe demonſtrations will be certainly falſe, though they ſhould be ſupported by all the powers of geometry.

FURTHER OBSERVATIONS ON PROJECTILES.

The air preſſes as much upon the back-part of the ball, as it reſiſts on the fore-part; and, of conſequence, a ball moving through the air with any degree of velocity, ought to be as much accelerated by the action of the air behind, as it is retarded by the action of that before. Here, then, it is natural to aſk, If the air accelerates a moving body as much as it retards it, how comes it to make any reſiſtance at all? yet certain it is that this fluid doth reſiſt, and that very conſiderably. To this it may be anſwered, that the air is always kept in ſome certain ſtate or conſtitution by another power which rules all it's motions, and it is this power, undoubtedly, which gives the reſiſtance. It is not to our purpoſe, at preſent, to inquire what that power is; but we ſee that the air is often in very different ſtates: one day, for inſtance, it's parts are violently agitated by a ſtorm, and another, perhaps, they are comparatively at reſt in a calm. In the firſt caſe, nobody heſitates to own, that the ſtorm is occaſioned by ſome cauſe or other which violently reſiſts any other power that would prevent the agitation of the air. In a calm the caſe is the ſame; for it would require the ſame exertion of power to excite a tempeſt in a calm day, as to allay a tempeſt in a ſtormy one. Now it is evident, that all projectiles, by their motion, agitate the atmoſphere in an unnatural manner; and conſequently are reſiſted by that power, whatever it is, which tends to reſtore the equilibrium, or bring back the atmoſphere to it's former ſtate.

If no other body beſides that above-mentioned acts upon projectiles, it is probable, that all reſiſtance to their motion would be in the duplicate proportion of their velocities; and accordingly, as long as the velocity is ſmall, we find it generally is ſo; but when the velocity comes to be exceedingly great, other ſources of reſiſtance ariſe. One of theſe is a ſubtraction of part of the moving power; which, though not properly a reſiſtance, or oppoſing another power to it, is an equivalent thereto. This ſubtraction ariſes from the following cauſe. The air, as we have already obſerved, preſſes upon the hinder part of the moving body by it's gravity, as much as it reſiſts the fore-part of it by the ſame property: nevertheleſs, the velocity with which the air preſſes upon any body by means of it's gravity is limited; and it is poſſible that a body may change it's place with ſo great velocity, that the air hath not time to ruſh in upon the back-part of it, in order to aſſiſt it's progreſſive motion. When this happens to be the caſe, there is, in the firſt place, a deficiency of the moving power equivalent to fifteen pounds on every ſquare inch of ſurface; at the ſame time that there is a poſitive reſiſtance of as much more on the fore-part, owing to the gravity of the atmoſphere, which muſt be overcome before the body can move forward.

This deficiency of moving power, and increaſe of reſiſtance, do not only take place when the body moves with a very great degree of velocity, but in all motions whatever. It is not in theſe caſes perceptible, becauſe the velocity with which the body moves, frequently bears but a very ſmall proportion to the velocity with which the air preſſes in behind it. Thus, ſuppoſing the velocity with which the air ruſhes into a vacuum to be 1200 feet in a ſecond, if a body moves with a velocity of 30, 40, or 50 feet in a ſecond, the force with which the air preſſes on the back-part is but $\frac{1}{25}$ at the utmoſt leſs than that which reſiſts on the fore-part of it, which will not be perceptible; but if, as in the caſe of bullets, the velocity of the projectile comes to have a conſiderable proportion to the velocity wherewith the air ruſhes in behind it, then a very perceptible, and otherwiſe unaccountable reſiſtance is obſerved, as we have ſeen in the experiments already related by Mr. Robins. Thus, if the air preſſes in with a velocity of 1200 feet in a ſecond, if the body changes it's place with a velocity of 600 feet in the ſame time, there is a reſiſtance of 15 pounds on the fore-part, and a preſſure of only 7½ on the back-part. The reſiſtance, therefore, not only overcomes the moving power of the air by 7½ pounds, but there is a deficiency of other 7½ pounds, owing to the want of half the preſſure of the atmoſphere on the back-part, and thus the whole loſs of the moving power is equivalent to 15 pounds; and hence the exceeding great increaſe of reſiſtance obſerved by Mr. Robins, beyond what it ought to be, according to the common computations. The velocity with which the air ruſhes into a vacuum is therefore a deſideratum in gunnery. Mr. Robins ſuppoſes that it is the ſame with the velocity of ſound; and that when a bullet moves with a velocity greater than that of 1200 feet in a ſecond, it leaves a perfect vacuum behind it. Hence he accounts for the great increaſe of reſiſtance to bullets coming with ſuch velocities; but as he doth not take notice of the loſs of the air's moving power, the anomalies of all leſſer velocities are inexplicable on his principles. Nay, he even tells us, that Sir Iſaac Newton's rule for computing diſtances may be applied in all velocities leſs than 1100 or 1200 feet in a ſecond, though this is expreſsly contradicted by his own experiments.

Though, for theſe reaſons, it is evident how great difficulties muſt occur in attempting to calculate the reſiſtance of the air to military projectiles, we have not even yet diſcovered all the ſources of reſiſtance to theſe bodies, when moving with immenſe velocities. Another power by which they are oppoſed (and which at laſt becomes greater than any of thoſe hitherto mentioned), is the air's elaſticity. This, however, will not begin to ſhew itſelf in the way of reſiſtance, till the velocity of the moving body becomes conſiderably greater than that by which the air preſſes into a vacuum. Having, therefore, firſt aſcertained this velocity, which

h we ſhall ſuppoſe to be 1200 feet in a ſe-
l, it is plain, that if a body moves with a velo-
of 1800 feet in a ſecond, it muſt compreſs the
efore it; becauſe the fluid hath neither time
xpand itſelf, in order to fill the vacuum left
nd the moving body, nor to ruſh in by it's
ity. This compreſſion it will reſiſt by it's
c power, which thus becomes a new ſource of
ance, increaſing, without any limit, in pro-
on to the velocity of the moving body. If now
uppoſe the moving body to ſet out with a
ity of 2400 feet in a ſecond, it is plain that
is not only a vacuum left behind the body,
the air before it is compreſſed into half it's
al ſpace. The loſs of motion in the pro-
le, therefore, is now very conſiderable. It
loſes fifteen pounds on every ſquare inch of
ce, on account of the deficiency of the moving
r of the air behind it; then it loſes fifteen
ds more, on account of the reſiſtance of the
efore it; again it loſes fifteen pounds, on ac-
t of the elaſticity of the compreſſed air; and,
, another fifteen pounds on account of the
um behind, which takes off the weight of the
ſphere, that would have been equivalent to
half of the elaſticity of the air before it. The
e reſiſtance, therefore, upon every ſquare inch
urface moving with this velocity is ſixty
ds, beſides that which ariſes from the power
ing to preſerve the general ſtate of the at-
here, and which increaſes in the duplicate
ortion of the velocity, as already mentioned.
e body is ſuppoſed to move with a velocity of
feet in a ſecond, the reſiſtance from the air's
city will then be quadrupled, or amount to ſixty
ds on the ſquare inch of ſurface; which, added
e other cauſes, produces a reſiſtance of 105

pounds upon the ſquare inch; and thus would the reſiſtance from the elaſticity of the air go on continually increaſing, till at laſt the motion of the projectile would be as effectually ſtopped as if it was fired againſt a wall. This obſtacle, therefore, we are to conſider as really inſuperable by any art whatever, and therefore it is not adviſeable to uſe larger charges of powder than what will project the ſhot with a velocity of 1200 feet in a ſecond. In this velocity the elaſticity of the air will not make great reſiſtance, if indeed it do make any at all; for though Mr. Robins hath conjectured, that air ruſhes into a vacuum with the velocity of ſound, or between 1100 and 1200 feet in a ſecond, yet we have no deciſive proof of the truth of this ſuppoſition. At this velocity indeed, according to Mr. Robins, a very ſudden increaſe of reſiſtance takes place; but this is denied by Mr. Glenie, who ſuppoſes that the reſiſtance proceeds gradually: and indeed it ſeems to be pretty obvious, that the reſiſtance cannot very ſuddenly increaſe, if the velocity is only increaſed in a ſmall degree. Yet it is certain, that the ſwifteſt motions with which cannon-balls can be projected are very ſoon reduced to this ſtandard; for Mr. Robins acquaints us, that " a twenty-four pound ſhot, when diſcharged with a velocity of 2000 feet in a ſecond, will be reduced to that of 1200 feet in a ſecond, in a flight of little more than 500 yards."

CONCERNING PENDULUMS.

A *pendulum* is a heavy body hanging to a ſmall cord or wire, which is moveable upon a center. It is that well known inſtrument ſo uſeful in meaſuring time, and aſcertaining with accuracy it's nicer diviſions.

A body thus ſuſpended being put in motion, deſcribes an arch; in one half of which it deſcends, and aſcends in the other.

For inſtance, here is a pendulum, that is, a heavy body, P, *fig.* 11, *pl.* 2, hanging by a ſmall thread, and moveable therewith about this point, B, to which the thread is fixed. If when the thread is ſtretched the weight be raiſed as high as C, and thence let fall, it will by it's own gravity deſcend through the arch C P as low as poſſible.

If it were entirely free, and not retained by the thread, it would fall in a vertical line, P L, from the point where I held it; but being retained by the ſtring, it can only partially obey the action of gravity, and is conſtrained to deſcribe an arc, C P.

The body in falling from C to P through the arc C P, acquires as much velocity (motion) as it would have acquired in falling perpendicularly from E to P, conſequently enough to carry P to the ſame height, through the ſame curve, in equal time, ſuppoſing the direction to be changed without affecting the velocity.

The thread is the cauſe which changes the direction impreſſed on the body without affecting the velocity; not conſidering, for the preſent, the effect of friction at the point of ſuſpenſion.

The body, when arrived at P, the loweſt point of the curve, cannot deſcend to the earth, becauſe it is withheld by the ſtring, but it retains all the velocity it has acquired in falling from C to P; ſo that if at this inſtant gravity ceaſed to act on this body, and that it was no longer withheld by the ſtring, it would go on, by the firſt law of motion, in a line P D tangent to the circle C P, in which the body moves: but the thread oppoſing an invincible obſtacle to it's gravity, and the force which it has acquired, to go on in the tangent

P D, it only endeavours to fly off in this tangent; the thread drawing it back, and the impreſſed force puſhing it on, it attempts to move in the direction of another tangent, which it is again withheld from purſuing by the thread; and by thus cauſing it continually to change it's direction, it deſcribes the arc P R, equal to C P.

When the body has arrived at R, all the force it had acquired is expended, and it falls again by it's gravity from R to P; from whence it again aſcends to P, and then deſcends again. And thus it will continue it's motion backwards and forwards along the curve, which motion is called an *oſcillatory* or *vibratory* motion; and each ſwing from C to R, as alſo from R to C, is called a *vibration*, or *oſcillation*.

The body being retained by the thread in the circumference of the circle C P M, of which the thread is the radius, the arc C P R, that it deſcribes, will be the arc of a circle.

You ſee clearly, that the thread by which the body is ſuſpended is an obſtacle that oppoſes in part it's deſcent towards the earth, and changes the direction in which it moves; but, at the ſame time, you ſee, that it is gravity which is the cauſe of it's motion or vibrations.

An horizontal line, perpendicular to the plane of the oſcillations, and paſſing through the point B, about which the pendulum oſcillates, is called the *axis* of oſcillation; the point B, to which the thread is fixed, is called the *point of ſuſpenſion*.

In conſidering pendulums, it is cuſtomary to ſuppoſe the weight of the body to be concentrated in one point.

Pendulums may be ſimple or compound.

Simple pendulums are thoſe to which only one weight is ſuſpended: *compound pendulums* are thoſe

to

which ſeveral weights are fixed; theſe are placed at different diſtances from the point of ſuſpenſion.

If the pendulum ſuffered no retardation in it's motion from the reſiſtance of the air, nor from the friction of the thread againſt the center about which it moves, the *arches* deſcribed in each vibration would be *exactly equal*, and *the motion of the pendulum would continue for ever.*

But as the motion of the pendulum is continually retarded by theſe cauſes, the arches deſcribed in each vibration muſt grow leſs and leſs continually, and at laſt vaniſh together with the motion of the pendulum.

The vibrations of one and the ſame pendulum, vibrating in unequal circular arches, are performed very nearly in equal times, provided the arches are but ſmall.

Thus in the pendulum A B, *fig.* 20, *pl.* 2, the vibration through the arch C A D, is performed very nearly in the ſame time wherein the pendulum vibrates through the arch E A F, on the ſuppoſition that the arches C A and E A are very ſmall.

Now as the arches are very ſmall, they will not differ much, either in length or declivity, from their reſpective chords; conſequently the times of deſcribing the arches, by a heavy body running along them, will be nearly equal to the times of deſcribing the chords: but I have already ſhewn you, that the times of deſcribing the chords are equal; wherefore the times of deſcribing the arches C A, E A, muſt be nearly equal; and ſo likewiſe muſt be the double of thoſe times, or the times wherein the pendulum vibrates through the unequal arches C A D and E A F.

To render this clearer, let us recur to a diagram, to ſhew that the velocities of the bodies which oſcillate in different arcs, C B, D B, *fig.* 12, *pl.* 2, *pl.* 2, are, when they are arrived at the point B, as the chords of the arc they have deſcribed. Draw the horizontal lines C F, D E. Now I have ſhewn you, that the velocity bodies acquired in falling through the arcs C B, D B, are the ſame as they would have acquired in falling perpendicularly from F to B, and from E to B. Now the velocity acquired in falling from F to B, is to the velocity acquired in falling from G to B, in a ſubduplicate ratio of F B to G B, or as the line C B to G B. In the ſame manner, the velocity acquired by a body in falling from E to B, is to that it would have acquired in falling from G to B, in a ſubduplicate ratio of E B to G B, or as D B to G B; and, conſequently, the velocity acquired in falling from F to B, is to that acquired in falling from E to B, as the chord C B is to the chord D B; that is, the velocities acquired in falling through the arcs, are as their reſpective chords.

From hence it is clear, that if in the circle G B you take the arcs B 1, B 2, B 3, of which the chords are reſpectively as 1, 2, 3, &c. the velocities of a pendulum deſcending ſucceſſively through the arcs B 1, B 2, B 3, &c. will be as 1, 2, 3, &c. that is, as the reſpective chords.

This you may confirm by experiment. Here are two pendulums of an equal length; I will let them go at the ſame inſtant of time, but in ſuch manner that they may vibrate through ſmall but unequal arches. They will for a long time keep pace together, and continue to begin and end their ſwings, without any ſenſible difference as to point of time, during a great number of vibrations.

It is the characteriſtic of real genius to diſtinguiſh facts one from another, and to draw important conſequences from what would be of no value to others. Thus *Galileo*, conſidering the oſcillations of a lamp ſuſpended from a roof; a circumſtance that had often been attended to before, but to little purpoſe. It had ſpoke an unknown language to all who had hitherto obſerved it, but not ſo to *Galileo;* he perceived that it's vibrations were apparently equal, though their extent continually diminiſhed, till the motion of the lamp entirely ceaſed : this phenomena, which is called the *iſochroniſm of pendulums*, appeared to him important and uſeful. He perceived alſo, that, every thing elſe remaining the ſame, the vibrations were ſlower, in proportion as the lamp was further from the point of ſuſpenſion; and ſaw that, by theſe obſervations, he was furniſhed with an inſtrument proper to meaſure what we call *time;* an inſtrument which always gave equal intervals: and that he could increaſe or diminiſh theſe intervals at pleaſure, by making the pendulum longer or ſhorter; and thus obtain an accurate *chronometer*, or inſtrument for meaſuring time.

You have ſeen it proved, by the experiments with Mr. Atwood's machine, that a falling body deſcribes ſpaces which are as the ſquares of the times employed in falling, or the velocity acquired at the end of each of theſe times.

Now in the vibrations of a pendulum, the ſpaces deſcribed are arches of a circle, whoſe radius is the length of the pendulum. Let there be two pendulums, A B, C D, *fig.* 13, *pl.* 2, vibrating in ſimilar arches, E B F, G D H. The time of a vibration of the pendulum A B, will be to the time of a vibration of the pendulum C D, in a ſubduplicate ratio of the length A B to the length C D. Now as the arches are to each other as the radii; and, from the foregoing principle, the time of a vibration in the arch E B, is to the time of a vibration in the arch G D, in a ſubduplicate ratio of E B to G D, it follows, that theſe, or, in other words, *the times of the vibrations of pendulums that deſcribe ſimilar arcs of circles, or which have equal angles of vibration, are as the ſquare roots of the lengths of the pendulums;* ſo that if one pendulum be four times as long as another, the ſhorter will vibrate in half the time, ſo as to perform two vibrations in the ſame time that the longer performs one. Again, if one pendulum be nine feet long, and another four, the ſquare roots of which lengths are three and two, the ſhort one will make three vibrations while the other is making two.

A diſproportion in the length of two pendulums, occaſions a great difference, you ſee, in the times of their vibrations.

Of ſeveral pendulums vibrating in ſimilar arcs, the vibrations of the longeſt are ſlower than thoſe of the ſhorter ones; and, conſequently, if a pendulum is required that ſhall vibrate ſeconds, it muſt have a determinate length, as the length of the pendulum fixes the time of it's oſcillation. This length has been aſcertained to be thirty-nine inches.

From this principle, you may find how long a branch is which hangs down from the roof of a church; and, conſequently, by meaſuring from the ball of the branch to the floor, and adding this to the length of the branch, you may find how high the church is. Let us ſuppoſe the branch to vibrate once in three ſeconds; then, ſince the times of vibration are as the ſquare root of a pendulum's length, it follows, that the lengths of pendulums are as the ſquares of the times of vibration; and that the length of the branch is to the length of a pendulum which performs a vibration in one ſecond, as the ſquare of 3 to the ſquare of 1, or as 9 to 1. Now the length of a pendulum that vibrates ſeconds being 39 inches, multiplying this by 9, we obtain 352 inches 8 parts, for the length of the branch.

Pendulums which are of the ſame length vibrate in the ſame time, whatever be the proportion of their weights; or, in other words, the time of a pendulum's vibration is no way altered by varying the weight thereof. This follows from the property of gravity, which is always proportional to the quantity of matter; conſequently all bodies in the ſame circumſtances are moved by the force of gravity with the ſame velocity. To confirm this by experiment, here are two unequal weights, ſo ſuſpended by two threads, as to conſtitute two pendulums equal in length. Let them at the ſame inſtant of time fall from equal heights, they will keep pace together ſo as to perform their vibrations in equal times.

From the motion of a pendulum, it is clear that, in any one place, *the quantity of gravitating matter, in any body, is proportional to it's weight.* For we find by experiment, that pendulums of equal length, whatever quantities of matter they contain, vibrate in the ſame time. They have equal velocities in the ſame time: the velocity and time being given, the quantity of matter is as the force of gravity.

What I have hitherto ſaid on this ſubject, extends only to ſimple pendulums; that is, thoſe to which only one weight is ſuſpended, and where the thread by which it is ſuſpended is conſidered as without gravity or weight: for when the rod by which the weight is ſuſpended is of any conſiderable weight, the pendulum muſt be conſidered as compounded, for the weight of the rod has the ſame effect as a ſecond weight faſtened to the ſame thread. And I defined a compound pendulum, as one to which ſeveral weights were fixed, at invariable diſtances one from the other, as well as from the point of ſuſpenſion.

Compound pendulums follow the ſame laws as thoſe that are ſimple, only with ſome modifications.

OF THE CENTER OF OSCILLATION.

To determine the times of the vibrations of a compound pendulum, we muſt conſider a thing of which I have not yet ſpoken to you; that is, *the center of oſcillation.*

The *center of oſcillation* of a compound pendulum, is that point in which the efforts, or actions, of the weights which compoſe it are united, to cauſe the pendulum to vibrate in a certain time; or, in more technical terms, the center of oſcillation is that point of a pendulum, on each ſide of which the quantities of motion are equal, or in which all the gravity of the pendulum might be collected, without altering the time of it's vibrations. Though the *center of oſcillation* be different from the *center of gravity*, yet is it evident, from theſe definitions, that they have a neceſſary relation to each other.

The center of oſcillation of a ſimple pendulum, whoſe thread is conſidered without weight, is not in the center of gravity, but a little below it; but in the line of direction it is nearer or further from the center of gravity, according to a certain proportion between the radius of the ball forming the pendulum, and the length of the thread by which it is ſuſpended. Mr. Huygens has ſhewn how to find the center of oſcillation from the proportion between the radius of the weight and the length of the pendulum.

The real length of a ſimple pendulum is not, therefore, the ſame as the length of the thread from the point of ſuſpenſion to the ball attached to it, nor even to the center of gravity thereof; but it's length is to be eſtimated from the point of ſuſpenſion to the center of oſcillation, which differs from the center of gravity, except when the length of the thread exceeds to a certain degree the radius of the ball, when the difference becomes inſenſible.

When the line of the pendulum is poſſeſſed of weight which becomes ſenſible with reſpect to that which is attached to it, the center of oſcillation is no longer in the ſuſpended ball, but in a point ſomewhat above it; and this point is further removed from the ball in proportion as the weight of the rod is heavier when compared to the weight of the ſuſpended ball.

In this caſe the true length of the pendulum, is the diſtance between the point of ſuſpenſion and the center of oſcillation, and the vibrations of this pendulum will be quicker than if the rod were without weight, becauſe the pendulum is ſhorter.

You have ſeen that the longer the pendulum, or the further the weight from the point of ſuſpenſion, the ſlower are it's vibrations. Thus if to an inflexible line A C, *fig.* 14, *pl.* 2, 4 feet long, from whoſe extremity a weight P is ſuſpended, you add at Q a ſecond weight B ſomewhat higher than the other, as 3 feet from the point of ſuſpenſion; now the weight P, which is 4 feet from the point of ſuſpenſion, ought to make it's vibrations ſlower than the body B, which is only three feet therefrom: but as they are both attached to the ſame inflexible line, they are forced to perform their vibrations in the ſame time, which will be between the ſlowneſs with which it would have vibrated if there had been only the weight at A, and the greater velocity of it's vibrations if there had been only can give thus much, why not all the reſt? Why muſt it leave the body at one point of the tangent line, and not continue to act upon it in the ſame line? If the cauſe and the effect can be kept together ever ſo little beyond the perpendicular line, the difficulty is over, and the body performs the whole courſe of it's vibrations by one and the ſame cauſe; and the reciprocations we obſerve in the moving body, are occaſioned by a *medium*, whoſe vibrations are continued with infinite freedom.

This is ſurely more ſatisfactory than that ſpecies of reaſoning which aſſigns *a cauſe* for one half of the motion, and a *law* (which cannot execute itſelf) to account for the other half; and that ſays there is a certain mathematical point at which they are miraculouſly changed one for the other.

If the difficulty of making a body riſe by gravity ſhock you, word the matter differently, and ſay it *riſes by the cauſe of gravity.*

Motion is either a *cauſe* or an *effect:* it cannot be a cauſe for this reaſon, that nothing can be the cauſe of itſelf; and if you allow it to be an effect, then all the conſequences follow.

Sometimes our corporeal ſenſes are able to diſcover the relation between the effect and it's proper cauſe, and ſometimes cauſes are to be inferred by rational induction grounding itſelf on paſt experience.

Thus when the mercurial fluid riſes an inch higher to day in the tube of a barometer than it ſtood yeſterday, you neither ſee nor feel the cauſe of this alteration, but you diſcover the cauſe by very ſure deduction; for we know that the Toricellian vacuum is filled by the column of mercury, till the mercury becomes a counterballance to the preſſure of the external air; and that the air is the impelling cauſe which drives the mercury up into the tube, and keeps it ſuſpended there. Hence we conclude, that an alteration in the preſſure of the air has occaſioned an alteration in the tube, and that the preſſure of the atmoſphere being about $\frac{1}{30}$th part greater to-day than it was yeſterday, forces the mercury ſo much higher till it is in equilibrio therewith.

In the ſame manner moſt of the other motions that are in the world may be referred to their proper cauſes, either by immediate experiment or rational deduction.

It does not follow that no material cauſe is concerned in any particular effect, becauſe we neither ſee nor feel it's operation.

There are many obvious caſes, in which the cauſe of motion may be aſſigned with certainty, though it is not perceived by any of the outward ſenſes; and partly for this reaſon, becauſe that which is manifeſt in ſome inſtances is occult in others, and diſtinguiſhable only by rational deduction.

Thus when a thermometer is held before the fire, we diſcover by it's riſing that the fire enters the pores both of the glaſs and the incloſed fluid, and this being thereby expanded and increaſed in it's dimenſions, neceſſarily riſes higher in the tube. Here though we *feel* the element of fire by it's *heat*, and *ſee* it by it's *light*, yet it's effects are only to be diſcovered by rational deduction.

Motion is never to be conſidered as a thing by itſelf, but as an effect, which like all other effects muſt be referred to it's proper cauſes: and there is no occaſion to underſtand motion as the cauſe of it's own continuation, when there is an active medium adequate to all the effects of gravity, which moving with infinite freedom, can ſo far deceive us by the ſubtilty of it's vibrations, as to make us believe there is no cauſe where the moſt powerful of all ſecondary cauſes is preſent. If motion be an effect, this reaſoning is neceſſary and natural.

Before I proceed to the application of pendulums to clocks, it may not be amiſs to recapitulate their properties, as it is the only part of a clock which has a natural tendency to meaſure time.

A pendulum once put in motion would continue to vibrate equal arcs, if no external cauſe tend to deſtroy it's motion.

All thoſe equal vibrations would be performed in equal times.

Pendulums of equal lengths, though unequal weights, will *(cæteris paribus)* perform their vibrations in equal times.

A pendulum cannot reſt but when it's center of gravity is directly below it's point of ſuſpenſion.

The times wherein pendulums of any length perform their oſcillations, are as the ſquare roots of their lengths directly, and the ſquare root of the gravitating forces reciprocally.

If an iron bar be ſuſpended at one end and put into motion, the oſcillations will be performed in leſs time than by a ſingle pendulum of the ſame length: for the upper parts of the iron will endeavour to oſcillate according to their reſpective diſtances from the center of ſuſpenſion, and ſo accelerate the motion.

A ſingle pendulum, whoſe length is two thirds of the bar's length, will be found to perform it's oſcillations in equal times with the bar. Hence a point taken ⅓ of the length of the bar from the lower end, is called the center of oſcillation.

Hence it is evident,

1. That the bar oſcillates in the ſame manner as it would do if the gravity of all it's parts were

contracted into the center of oſcillation, and all it's other parts remained without gravity.

2. Therefore if any obſtacle ſtops the center of oſcillation, the whole motion of the bar is deſtroyed at once, and conſequently the whole force of it's motion is ſpent upon, and received by the obſtacle.

3. Therefore, the quantities of motion on each ſide the center of oſcillation are equal.

4. Therefore, if any other part of the bar ſtrikes againſt an obſtacle, the motion will not be deſtroyed immediately, but the center of oſcillation will endeavour to go on, and by that endeavour, either break or bend the bar.

From theſe particulars it is eaſy to explain the *center of percuſſion*, or what part of any inſtrument or weapon will ſtrike with the greateſt force. For if the ſtroke be not given with that part which is the common center of oſcillation of the weapon, and ſo much of the arm as moves with it (whether it be from the wriſt, elbow, or ſhoulder,) the whole force of the motion will not be ſpent upon that which receives the blow.

All oſcillating bodies, of what ſhape ſoever, have their proper centers of oſcillation; which, if the rod of the pendulum be ſmall, and the bob large, will fall within the bob.

By the length of a pendulum, is always meant the diſtance between the center of ſuſpenſion and the center of oſcillation.

If a pendulum be heated, it grows longer, and conſequently oſcillates ſlower.

Pendulums of the ſame length oſcillate ſlower the nearer they are brought to the equator, and that for two reaſons; becauſe the ſemidiameter of the earth's equator is about ſeventeen miles longer than the ſemiaxis of the earth; and becauſe of the centrifugal force (ariſing from the diurnal rotation)

which

which at the equator is the $\frac{1}{289}$ part of gravity, from whence it decreaſes continually, till at the poles it quite vaniſhes.

Much has been ſaid of the advantages of making a pendulum VIBRATE IN THE ARC OF A CYCLOID, *in which it would deſcribe the greateſt and leaſt entire vibrations in the ſame time*; but this property is only demonſtrated on a ſuppoſition that the whole maſs of the pendulum is concentrated in a point, but this cannot take place in any really vibrating body. And when the pendulum is of finite magnitude, there is no point given which determines the length of the pendulum; but on the contrary, the center of oſcillation will not occupy the ſame place in the given body, when deſcribing different parts of the track it moves through, but will continually be moved in reſpect of the pendulum itſelf during it's vibration. This prevents the determination of the time of the vibration in a cycloid, except in the above-mentioned imaginary caſes.

There are many other obſtacles which concur in rendering the application of this curve to the vibration of pendulums, a ſource of errors far greater than thoſe which it's peculiar property is intended to obviate. It is therefore wholly diſuſed in practice, and it would be only loſing time to dwell on it's peculiar properties.

To find the length of a pendulum, that ſhall make any number of vibrations in a given time.

Reduce the given time into ſeconds, then ſay, as the ſquare of the number of vibrations given : to the ſquare of this number of ſeconds : : ſo is 39.13 : to the length of the pendulum ſought, in inches.

Ex. Suppoſe it makes 50 vibrations in a minute; here a minute is = 60 ſeconds; then,

As 2500 (the ſquare of 50) : 3600 (the ſquare of 60) : : 39.13 : to the length $= \frac{3600 \times 39.13}{2500} = \frac{140868}{2500} = 56.34$ inches, the length required.

If it be required to find a pendulum that ſhall vibrate ſuch a number of times in a minute; you need only divide 140868, by the ſquare of the number of vibrations given, and the quotient will be the length of the pendulum.

If the pendulum is a thread with a little ball at it, then the diſtance between the point of ſuſpenſion and the center of the ball is eſteemed the length of the pendulum. But if the ball be large, ſay, as the diſtance between the point of ſuſpenſion, and the center of the ball, is to the radius of the ball; ſo is the radius of the ball to a third proportional. Set $\frac{2}{5}$ of this from the center of the ball downward, gives the center of oſcillation. Then the whole diſtance from the point of ſuſpenſion to this center of oſcillation, is the true length of the pendulum.

If the bob of the pendulum be not a whole ſphere, but a thin ſegment of a ſphere, as in moſt clocks; then to find the center of oſcillation, ſay, as the diſtance between the point of ſuſpenſion and the middle of the bob, is to half the breadth of the bob; ſo is half the breadth of the bob to a third proportional. Set one third of this length from the middle of the bob downwards, gives the center of oſcillation. Then the diſtance between the centers of ſuſpenſion and oſcillation, is the exact length of the pendulum.

Having the length of a pendulum given, to find how many vibrations it ſhall make in any given time.

Reduce the time given into ſeconds, and the pendulum's length into inches; then ſay, as the given length of the pendulum : to 39.13 : : ſo is the ſquare of the time given : to the ſquare of the

number of vibrations, whoſe ſquare root is
number ſought.

Example. Suppoſe the length of the pendul
is 56.34 inches, to find how often it will vib
in a minute.

1 minute = 60 ſeconds. Then 56.34 (
length of the pendulum) : 39.13 : : 3600 (the ſqu
of 60) : to the ſquare of the number of vibrati

$$= \frac{3600 + 39.13}{56.34} = \frac{140868}{56.34} = 2500\text{, and } \sqrt{250}$$

50 = the number of vibrations ſought.

If the time given be a minute, you need
divide 140868 by the length, and extract the
of the quotient for the number of vibrations.

OF TIME.

As time in itſelf does not fall under the
tice of our ſenſes, and as the parts thereof go o
a continued ſucceſſion one after another, no
exiſting together, it is impoſſible to diſcover
equality or inequality of any two portions of ti
by an immediate compariſon of one with
other.

It is therefore neceſſary, in order to diſting
the parts of time, to have recourſe to ſometh
ſenſible, and of a *different* nature from time,
meaſure thereof.

In the firſt ages of the world, men obſer
the frequent riſing and ſettings of the ſun, took
one or the other for their firſt meaſure of ti
calling that portion of time which paſſed betw
the two riſings or ſettings, which immediately
ceeded each other, by the name of a *day*. In
manner, it is rational to ſuppoſe, that obſerving
frequent returns of the new and full moons,
made the one or the other their ſecond meaſur
time, calling that ſpace which paſſed between

ſucceſſive new or full moons, by the name of a *moon* or *month*. For ſome time they contented themſelves with thoſe meaſures, without knowing or conſidering whether they were accurate or inaccurate.

In proportion as ſcience dawned upon the human mind, men became better acquainted with the motion of the heavenly bodies; they then diſcovered irregularities in the apparent motion of the ſun, and of conſequence an inequality in the natural days which depend on that motion. By conſidering the cauſes of this inequality, they were led to make ſuch alterations in the natural days, by adding to ſome and taking from others, as reduced them all to a mean equal length, each day being made to conſiſt of 24 equal hours, each of which is ſubdivided into 60 equal parts called minutes, and theſe into 60 other equal parts called ſeconds, and ſo on in a ſexageſimal progreſſion; and theſe parts of time thus reduced to an equality, conſtitute the mean or equal time, as it ſtands diſtinguiſhed by *aſtronomers* from the unequal or apparent time, as meaſured by the apparent motion of the ſun.

In order to have a conſtant meaſure of equal time, HUYGENS, a man who added the acuteſt penetration to the moſt indefatigable induſtry, contrived a method of adapting pendulums to clocks, whereby their motions are ſo exactly regulated, that in one whoſe movements are rightly adjuſted, the ſeconds, minutes, and hours, are for ſome time pointed out with the greateſt exactneſs.

The principle of motion in a clock is derived from the power either of a weight or ſpring; either of theſe forces is ſufficient to actuate or put in motion the ſyſtem of wheels and pinions which compoſe the intermediate parts of the clock; the indexes fixed on the axis point out the proper ſubdiviſions of time on appropriate circles upon the face of the clock; and a pendulum or ballance is added, to regulate or render uniform the motion communicated to the machine.

The force of the weight is derived from the power of gravity, and this being always the ſame in a given quantity of matter, the force of the weight may be conſidered as a conſtant quantity, or always remains the ſame in the ſame medium, and is therefore a uniform power or principle of motion.

If the pendulum be put in motion by a puſh of the hand, it will continue to move backward and forward till the reſiſtance of the air or the friction at the point of ſuſpenſion deſtroys the original impreſſed force. But at every vibration of the pendulum, the teeth of the crown wheel acts upon the pallets, ſo that after one tooth has *communicated* motion to one pallet, it eſcapes, and the oppoſite tooth acts upon the oppoſite pallet, and eſcapes in the ſame manner; and thus each tooth eſcapes after having communicated it's motion to the pallets in ſuch manner that the pendulum, inſtead of being ſtopped, continues to move.

Let E G F, *fig.* 15, *pl.* 2, repreſent the ſwing-wheel of a clock, that is to revolve in the direction E G F; let C and D repreſent the pallets moveable on an axis at A, and ſo connected with the pendulum as to be made to vibrate along with it. Suppoſe the ball to vibrate from R to B, one of the teeth of the wheel reſting againſt the pallet C, whoſe figure is ſeen enlarged at I K L; when the pendulum returns towards Q, the pallet c is drawn out, the wheel preſſing firſt along the plane I K, and afterwards on the inclined plane K L; the preſſure of the wheel on K L puſhes the pallet, or aſſiſts it's motion, till at length the tooth ſlips off the point L. During this time the pallet D, whoſe figure is ſeen at P N O, is carried in between the teeth on the other ſide of the wheel, ſo that when the wheel eſcapes from the pallet C, another tooth drops on the plane N P of the pallet D; the returning vibration again draws out the pallet, the tooth of the wheel aſſiſting it's motion by preſſing along the inclined plane N O till it eſcapes at O. At this inſtant the pallet c has acquired it's original ſituation, and therefore receives the adjacent tooth, and the whole proceeds as before.*

The piece of mechaniſm I have juſt deſcribed, is termed the *dead-beat eſcapement*, becauſe the ſecond hand, in clocks of this conſtruction, falls with a dead ſtroke without recoil on the diviſion line of the dial, and remains motionleſs during that part of the vibration in which the tooth reſts on the plane I K or P N of the pallet.

From hence it is eaſy for you to ſee, that it is, 1ſt, The weight that turns all the wheels, and at the ſame time continues the motion of the pendulum. 2d, That the quickneſs of the motion of the wheels is determined by that of the pendulum. 3. That the wheels point out the parts of time divided by the uniform motion of the pendulum.

Conſiderable irregularities in clock-work ariſe from the tenacity of the oil applied to the moving pivots, for the oil is leſs fluid in cold than in hot weather; and any diminution in it's fluidity tends to deſtroy the momentum which the pendulum had acquired, as well as to diminiſh the maintaining power by it's endeavour to overcome the rigidity of the cooled oil; the action on the pallets will therefore be leſs forcible, and the vibration will be leſs. To avoid this defect as far as relates to the ſuſpenſion of the pendulum, it is uſual to ſuſpend it by a ſtrait flexible ſpring, inſtead of an axis.

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* Nicholſon's Introduction to Natural Philoſophy, vol. i. p. 88.

In all that I have hitherto ſaid, the length of the pendulum of the clock has been conſidered as invariably the ſame; but the contrary happens in practice, for heat *dilates*, and cold *contracts* all metals, by which means the ſame pendulum is longer in ſummer than in winter, and the clock conſequently goes ſlower.

Various expedients have been thought of for correcting this imperfection; all of theſe, except one, depend on the oppoſing of expanſion to expanſion, in ſuch manner that the one ſhall ſhorten the pendulum as much as the other lengthens it.

The *only* method that does not depend on the above principle, is by making the pendulum rod of the ſtraiteſt grained wood, becauſe the longitudinal expanſion is ſo ſmall, that it anſwers with ſufficient accuracy for ordinary purpoſes. Deal wood makes very good pendulum rods; the wood called Sapadillo* is ſaid to be ſtill better; baking, varniſhing, gilding, or ſoaking theſe woods in any melted matter, is ſaid to render them leſs accurate, and that they ſhould be ſimply rubbed on the outſide with wax and a cloth.

Of the various contrivances to remedy this evil by contrary expanſion, I ſhall mention only one, namely, the *gridiron pendulum.*† The expanſion of braſs is allowed to exceed that of ſteel in the proportion of 5 to 3; on which ſuppoſition, if any piece of ſteel by the application of a certain degree of heat, expands $\frac{3}{10}$ of an inch, a piece of braſs of the ſame length will expand $\frac{5}{10}$ of an inch.

Now as the whole length of the braſs expands $\frac{5}{10}$ of an inch, and the expanſion *through the whole* is ſuppoſed uniform, if it be divided into five equal parts, each part will have expanded $\frac{1}{10}$ of an inch;

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* Cumming's Elements of Clock Work, p. 92.

† Nicholſon's Introduction to Philoſophy, vol. i. p. 91.

if, therefore, we take away two-fifths of it's whole length, the expanſion of the remaining three-fifths will be three-tenths of an inch; conſequently, the expanſion of a bar of ſteel is equal to the expanſion of a bar of braſs three-fifths it's length.

Let A B, *fig.* 16, *pl.* 2, repreſent the length of any given pendulum, to which a *gridiron* is to be applied. Biſect A B in C, and make B D, D E, E F, each equal to C B, the half of A B; then A F will be to B F, or H G, as 5 to 3.

If therefore A F be ſteel, and H G be braſs, their contractions and expanſions, with any degree of heat and cold, will be equal; and if the braſs bar G H be firmly attached to the ſteel bar, at their extremities E G, and the ſteel bar be ſuſpended by the point A, the braſs bar will expand upwards, as much as the ſteel bar H G downwards, and the points A and H will always keep the ſame diſtance from each other. *Conſequently,*

If a pendulum be conſtructed, whoſe point of ſuſpenſion is A, *and it's center of oſcillation* H, *it can neither be lengthened nor ſhortened by any change of heat and cold.*

It appears, that whatever be the length of a pendulum, three half lengths muſt be of ſteel, and one half length of braſs, in order to have as much expanſion upwards as downwards; and *when the whole length of bars is thus aſcertained*, they may be cut into ſuch ſeveral lengths as may beſt ſuit the purpoſe.

Always obſerving that the expanſion of the ſteel tends downwards, and that of the braſs upwards; in which caſe they will ballance each other, without regard to the number of pieces into which they are cut; for the effect of the whole conſiſts of the effects of all it's parts.

If the ſteel bar A F be cut into three unequal lengths, and the braſs bar H G into two, and thoſe five pieces be applied and connected with each other, as in *fig.* 17, *pl.* 2, *the braſs bars will expand upwards, as much as the ſteel downwards*; and the center of oſcillation, B, always keeps the ſame diſtance from A, the point of ſuſpenſion; nor will the expanſion of the little croſs pieces that connect the bars be of any effect, as they only act laterally.

Though in theory five bars only are neceſſary for conſtructing a gridiron, nine are requiſite in practice;* and in order that the bar, to which the pendulum is immediately ſuſpended, may be equally ſupported on each ſide. From *fig.* 19, *pl.* 2, you will ſee clearly, that the correſponding bars on each ſide the center co-operate in ſuch manner, as to move both ends of the croſs-bars equally, and by that means prevent ſuch bending of the upright ones, as muſt otherwiſe happen by the weight of the ball B. Theſe additional bars, properly applied, do not increaſe the expanſion.

Fig. 18, *pl.* 2, repreſents the manner of connecting the bars in a gridiron pendulum. The bars are repreſented as broke in the middle: the letters on the round bars denote the metal of which each is made; and that part of the middle rod which is above the croſs-piece E, ſerves only to keep the three bars on each ſide thereof in the ſame plane with the two outſide ones: it alſo anſwers a like purpoſe at the lower end of the gridiron, *and is pinned only at the croſs-piece* E; moving freely, *but without ſhake*, in the pieces C, D, F, and G. The upright bars are generally connected towards the middle by one or more croſs-pieces: to prevent any trembling that might ariſe from their elaſtic flexibility, theſe pieces are pinned to the two ex-

treme

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* On the ſuppoſition that ſteel and braſs are the metals uſed.

treme bars, and allow the other ſeven to move freely.

In all this it is ſuppoſed, that the expanſion of the braſs is to that of the ſteel exactly as five to three, and that all the dimenſions are accurately laid down. If the contrary appears, the gridiron may be adjuſted by ſhifting the croſs-piece F upwards or downwards, as occaſion may require.

Before we proceed to a freſh ſubject, I ſhall beg leave to ſay a few words on the nature of time; as, unleſs you are able to form abſtract ideas of time and ſpace, you will never truly apprehend ſpiritual ſubjects; whereas juſt notions thereof will throw very important light on religious and metaphyſical ſpeculations. "If nobody aſk me what *time* is," ſays St. Auguſtine, I think I know; but if ny body aſk me, I cannot tell:" and indeed it is ot eaſy to give a clear idea thereof. Are days, nd months, and years, deſcriptive of time? Days, and months, and years, are meaſured by the ws of motion; but the meaſure is different from, nd only relative to time. Time would be, were ays, and years, and months, to be confounded. ord Monboddo defines time as the meaſure of e duration of things that exiſt in ſucceſſion, by e motion of the celeſtial bodies.

All the ſubjects to which time is applicable, e ſaid to be in time; and are all, ſome way or her affected by time. But it is evident, that beings hich ſuffer no change in ſubſtance, qualities, nor ergies, cannot, without ſome reſtriction, be ſaid be in time. Of this kind we conceive the Dine Being to be.

For time cannot be applied to any being of ble and permanent duration, without change or riation of any kind; but only to beings that are a conſtant flux, and always changing, either as their ſubſtance, or their qualities and energies. The

Dr. Clarke, by confounding the ideas of ſucceſſive and unſucceſſive duration, advanced a ſtrange paradox, which he thus expreſſes: "How any thing can have exiſted eternally, that is, how an eternal duration can be actually paſt, is utterly unconceivable; and yet to deny that an eternal duration is now actually paſt, is an expreſs contradiction." Now he ſhould have ſaid quite the contrary; namely, that to maintain that an eternal duration is actually paſt, is altogether repugnant and contradictory. It is indeed not only unconceivable, but abſolutely impoſſible. Wherever there is a laſt, there muſt be a firſt: now in eternity there can be no firſt, and therefore no laſt. Whatever is ſucceſſive cannot be eternal: no addition of finite ſucceſſions can make abſolute infinite.

This ſubject cannot be conſidered too cloſely, if you wiſh to avoid the errors of modern materialiſts; for you will find one of them declaring, that he can eaſier admit the *non-exiſtence of God himſelf*, than the non-exiſtence of ſpace or duration: thus conceiving, as Mr. Hindmarſh has juſtly inferred, time and ſpace, which in themſelves are unſubſtantial, inanimate, and deſtitute of intelligence, to be more neceſſary and independent in their exiſtence, than him whom we call GOD.*

I will conclude this part of the preſent Lecture, with a ſhort extract from that part of Mr. Tucker's "Light of Nature" which he terms "The Viſion."—"And there ſtood before him an angel; his countenance was mild and lively, and his raiment white and ſhining. He had ſpangled wings growing from his ſhoulders, his ſides, and his legs. And he ſaid, 'O man, come along with me: I will

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* For a confutation of Dr. Prieſtley's notions on this and other ſubjects, ſee "Hindmarſh's Letters to Prieſtley."

‘ teach thee what to think of glories thou canſt not ‘ comprehend, and make thee more ſenſible of the ‘ infinite diſtance between the creature and the ‘ Creator.’ So ſaying, he took me up, and carried me to the utmoſt bounds of the univerſe. And he ſaid, ‘ Try now if thou canſt create a new world ‘ beyond this.’ And I ſaid, ‘ Far be it from me to ‘ attempt incroaching upon the divine prerogative. ‘ Thou knoweſt I am poor and weak, unable to act ‘ without corporeal inſtruments; and the little ‘ power I have, is given me.’ And he ſaid, ‘ I ‘ know thy weakneſs; that the power is not thine; ‘ nor do I expect that thou ſhouldeſt operate. I ‘ am commiſſioned for thine inſtruction. Know, ‘ then, that creative power awaits thy direction, ‘ for a trial of what thou canſt perform by it.’ ‘ Alas!’ ſaid I, ‘ I know not where to begin, nor ‘ how to proceed!’

And he ſaid, ‘ Stretch forth thy right-arm, and ‘ thruſt it ſtrait from thy ſide.’ And I eſſayed, but could not thruſt it out. Not that I found any thing to reſiſt me; but when my arm came to the utmoſt verge of the univerſe, it ſeemed as if I had loſt the uſe of it, ſo that I could not move it further. And I aſked the angel, ‘ Wherefore cannot ‘ I move my arm this way? I can thruſt it above or ‘ below, before or behind me; but I cannot ſtretch ‘ it out from my ſide.’ And he ſaid, ‘ Becauſe ‘ there is no ſpace to receive it.’ And I ſaid, ‘ Since it hath ſo pleaſed the creative power, and ‘ this for mine inſtruction, may there be ſpace.’ And he ſaid, ‘ Put forth thine arm again.’ And I put it forth with eaſe ſtrait from my ſide, as I could have done any other way.

And he ſaid, ‘ Wave now thy fingers to and fro; moving them in order, one after another.’ Accordingly, I endeavoured to do as I was bidden, but could not perceive whether my fingers moved

gins to be compreſſed, the force by which it
the ſtriking body, and accelerates the body
is the leaſt of all; it afterwards will cont
increaſe during each ſucceſſive inſtant,
compreſſion is the greateſt poſſible. The i
of this force may vary according to any ima
law; but whatever be the variation, it
equally on both ſides.

When the two bodies have acquired
mon velocity, the ſpring can acquire no
compreſſion, and may then begin to reſtor
with various degrees of force, from 0 to th
by which it was compreſſed. When th
tutive force is equal to that of compreſſion,
tion of the ſpring will be ſimilar to that of p
elaſtic bodies.

Motion cannot be communicated to an
inſtantaneouſly, but muſt be produced by
acceleration; it not being conceivable, th
really exiſting body ſhould paſs from qui
into finite motion, or from one degree o
motion to another, without having poſſe
the intermediate degrees of velocity.

Suppoſe a ſpherical body to impinge
ther body of the ſame form, moving in th
direction with the line which joins their

move with a greater velocity than that of the ball ſtruck, and the reſiſtance which the ſpheres oppoſe to the change of their figures, will act equally in both ſpheres, but in contrary directions; that is, the force by which the ſtriking body is reſiſted, will urge forward the body ſtruck; which, therefore, will be gradually accelerated, and the ſtriking ball retarded, until the centers are at their greateſt diſtance, the change of the bodies figures being then the greateſt; at which inſtant all acceleration of the ball ſtruck, and retardation of the ſtriking ball, ceaſes, and the two centers begin to go on with a common velocity.

This reaſoning, concerning colliſion of bodies, is equally applicable to the caſe in which both bodies are non-elaſtic, as when one is perfectly non-elaſtic, and the other perfectly hard. It is likewiſe equally applicable to the colliſion of bodies which are elaſtic in any degree, ſo far as regards the velocity communicated to the body ſtruck, during that ſmall but finite portion of time in which the figures of the ſpheres receive their greateſt change, their centers then beginning to go on with a common velocity in bodies of every kind of texture.*

OF ELASTICITY.

The action whereby bodies, whoſe figures are changed, reſtore themſelves to their former figure, is termed *elaſticity*. An elaſtic body is therefore one whoſe figure being changed, it recovers, or has a tendency to recover, it's figure.

There are in nature, as you have already ſeen, varieties of activities; in ſome of which the cauſes are rendered manifeſt by experimental inquiries; in others, and among theſe we may reckon elaſticity,

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* See Atwood on Rectilinear Motion.

city, where no cauſe at all is diſcoverable by the ſenſes.

A variety of experiments prove the exiſtence of an elaſtic force. The ſeparation of two bodies after impact, is a proof of elaſticity. Metals, ſemimetals, ſtones, gems, foſſils, cartilages, moſt fluids, as air, and even water, exert an *influence oppoſite* to the direction of the force compreſſing them, and diſcover a *tendency* to return to their natural ſtate; which tendency is in all of them imperfect, and leſs than the force impreſſed; but moſt perfect in glaſs, ivory, hardened ſteel, and cartilages.

Elaſticity is increaſed by augmenting the denſity of a body: thus metals are rendered more elaſtic by being beaten by a hammer; and their elaſticity, which was ſcarcely ſenſible before, by this proceſs becomes very ſenſible. Steel is more elaſtic when tempered, and it's denſity is increaſed in the ratio of 7809 to 7738.

Elaſticity is ſometimes increaſed by cold: thus the range of a cannon-ball is ſaid to be greater when the cannon is cold, than when heated; and the ſtring of a violin, or a ſteel lamina, is inflected, and alſo recovers it's ſituation, with leſs force in hot than in cold weather.

Metal fibres, and thin ſteel laminæ, exhibit no elaſticity, unleſs ſtretched to a certain degree, and inflected by a certain force; as appears from lax cords, which, if a little ſtretched, and removed from their natural ſtate, diſcover no tendency to return to it; and when the inflection of a fibre is very great, the influence of elaſticity ſeems to be in ſome caſes annihilated; as appears by the fibres of wood, which, inflected to a certain degree, remain quieſcent, and have no tendency to recover their former ſituation. The limits where the elaſtic power begins, or where it terminates, are unknown.

Motion is ſuppoſed to be communicated, or diffuſed, in elaſtic bodies, from the point of impact to the remote parts; and this ſuppoſition is grounded on the following experiments.

Here are two ivory balls ſuſpended, ſo that their centers are in one line. The ſurface of one of them, B, is freſh painted. By letting them touch each other gently, A has received a ſmall point of paint upon it's ſurface. Now I ſhall raiſe the ball A, ſo that it may impinge with ſome violence on B, and it is evident that the ſurface of each ball has been flattened by the blow; for there is on each a circular mark, ſhewn by the paint ſtruck off, and the other by the paint received; and as the balls retain their ſpherical figure after the impact, it is clear that the parts of the ſurface not only loſt, but recovered their figure.

Two glaſs balls may, with a proper degree of velocity, ſo impinge on each other, that the interior parts of the ball will be broken, though the exterior, contiguous to the point of impact, be unbroken.

Suſpend two ivory balls from the ſame point, by ſtrings of the ſame length, and let the ſmaller ball, A, impinge upon B, at reſt, with a given velocity. A will be reflected always to the ſame height, and B will be impelled to the ſame height. But if either A or B be hollowed, and lead inſerted n the center, or near to the poſterior ſurface, neither ball, though the weight be the ſame, will aſcend as high as before the inſertion of the lead. The progreſſive motion of the parts from the point of impact is ſtopped by the inſertion of the ead; and, conſequently, the force of reſtitution, and he change of figure, is leſs than before it was inſerted.

The motion diffuſed from the point of impact to the remote parts of an elaſtic body, is con-

tinued

tinued for ſome time, and diminiſhes gradually till it vaniſhes. And there ſeem to be two kinds of vibrations in the parts of an elaſtic body; one of which is quick, and called a tremor of it's minute parts; and the other ſlower and longer, by which it's figure is changed, and an impinging body repelled.

A ſtroke or friction upon the edge of a glaſs, communicates a tremulous motion to the parts of the glaſs, which is viſibly communicated to the water. A reed or ſtick placed acroſs the bottom of a large glaſs bell, will fall when the glaſs is ſtruck, the ſtroke producing a change of figure. If you hold a piece of metal near the brim or lip of a bell, without touching it, and the bell be ſtricken by a hard body, you will ſee it touch the piece of metal, and will hear a ſucceſſion of ſounds gradually decaying. If the edge of the bell be pinched, and the fingers be ſuddenly withdrawn, the ſame ſound is heard, without producing any ſenſible motion towards the piece of metal, or diſplacing the reed acroſs it,

Thoſe *laws* according to which alterations are produced in the reſt and motion of bodies upon their colliſion, are called the *laws of the communication of motion.*

When one body ſtrikes againſt another, if the line of direction of the impulſe paſſes through the center of gravity of both the bodies, the impulſe is called *full* or *direct*, otherwiſe it is called an oblique impulſe.

The relative velocity of two bodies, is that velocity with which they approach to, or recede from, each other; and is equal either to the difference of the velocities of bodies moving the ſame way, or to the ſum of the velocities of bodies moving contrary ways: for if one of the bodies were at reſt, and the other moved towards it, or from it, with the forementioned difference or ſum of velocities, the body in motion would approach to, or recede from, the body at reſt, juſt as faſt as the two moving bodies approached to or receded from each other.

If two bodies move in the ſame direction with equal velocities, they are relatively at reſt.

When the impulſe is direct, and the bodies are void of elaſticity, the laws of the communication of motion are theſe that follow:

1. In all caſes, the velocities after the ſtroke are equal; for the impulſe ceaſes when the impinging bodies are relatively at reſt, and not before.

2. If two bodies move the ſame way, and in the ſame right line, that which moves faſteſt will overtake the other, and the ſum of their motions will be the ſame after the ſtroke as before: for, by the third law of motion, ſo much motion as the ſloweſt body gains, the ſwifteſt body loſes.

3. If two bodies move contrary ways, the ſum of their motions after the ſtroke, will be equal to the difference of their motions before the ſtroke: for whilſt the ſtrongeſt motion deſtroys the weakeſt, it loſes alſo an equal part of itſelf, by the third law of motion.

4. If the ſum of two conſpiring motions, or the difference of two contrary motions, be divided by the ſum of the quantities of matter in both the moving bodies, the quotient will give their common velocity after the ſtroke.

5. If the velocity after the ſtroke be multiplied into the quantity of matter in each body, the products will expreſs the quantities of motion in each body after the ſtroke.

6. The difference between the quantities of motion in either of the moving bodies, before and

after the ſtroke, is equal to the quantity of the ſtroke.

Example 1. Let a ball of three ounces, moving with nine degrees of velocity, overtake another ball of two ounces, moving with four degrees of velocity; then will the quantities of motion before the ſtroke be 27 and 8, the common velocity after the ſtroke will be 7, the quantities of motion after the ſtroke will be 21 and 14, and the quantity of the ſtroke will be 6.

Example 2. Let the ſame balls move with the ſame velocities contrary ways; then will the quantities of motion before the ſtroke be as before; the common velocity after the ſtroke will be $3\frac{4}{5}$, the quantities of motion after the ſtroke will be $11\frac{2}{5}$ and $7\frac{1}{5}$, and the quantity of the ſtroke $15\frac{3}{5}$.

Wherefore, if two equal bodies move in contrary directions, with equal velocities, as ſoon as they ſtrike both the motions will be deſtroyed. And if a body in motion ſtrikes againſt an equal body at reſt, it will communicate half it's velocity, or half it's motion. And if one moving body overtakes another moving body equal to the firſt, the common velocity after the ſtroke will be equal to half the difference of their velocities before the ſtroke. But if they moved in contrary directions, the velocity after the ſtroke will be equal to half the ſum of the velocities before the ſtroke.

7. If a moving body ſtrikes againſt an immoveable obſtacle, after the ſtroke the whole motion will be deſtroyed, and the quantity of the ſtroke will be equal to the whole quantity of the motion.

8. If the moving body gravitates towards the immoveable obſtacle (as when a ſtone falls upon the

earth), the quantity of the ſtroke is equal to the ſum of the quantity of motion added to the weight of the moving body; for the weight remains upon the obſtacle when the impulſe is deſtroyed.

The ſum of the motions of two bodies void of elaſticity, may be leſs after the ſtroke than it was before, but it cannot be more.

9. If a body moves after the ſtroke the ſame way that it moved before, the difference of the velocities before and after the ſtroke will be equal to the velocity loſt or gained. Thus, in the firſt example, the velocity loſt is 2, and the velocity gained 3.

10. If the direction of the motion, after the ſtroke, be contrary to the direction of the motion before the ſtroke, the ſum of the velocities before and after the ſtroke will expreſs the quantity of the velocity gained. Thus in the ſecond example, the velocity loſt is 5½, the velocity gained 7½.

When the impulſe is direct, and the bodies perfectly elaſtic, the laws of the communication of motion are different from the foregoing. For,

1. Upon the colliſion of two elaſtic bodies, the force of elaſticity is equal to the force of compreſſion; and the force of compreſſion in each body is equal to the quantity of the ſtroke.

2. The whole force of elaſticity, exerted at the reſtitution of both the ſprings, is double the quantity of the ſtroke; for it is the reſult of two forces in contrary directions, each of which is equal to the quantity of the ſtroke. Or it may be conceived thus: the ſum of the elaſticities is equal to the ſum of the quantities of the ſtroke in both bodies together; that is, to double the quantity of the ſtroke in each ſingle body.

3. The effect of the elaſticity in each body will be equal to the effect of the ſtroke, and in the ſame direction; for the two equal and contrary

elaſticities in the former caſe, are equivalent to action and re-action in the latter.

4. Wherefore, to find the velocity of either body after the colliſion, firſt, find the common velocity with which the bodies would move after the ſtroke, if they had been void of elaſticity, and find alſo the velocity loſt or gained; then ſubtract the velocity loſt from the common velocity, or to the common velocity add the velocity gained; ſo ſhall the difference, or ſum, be the velocity ſought. But if the velocity loſt be greater than the common velocity, then ſubtract the common velocity from the velocity loſt, and the remainder will give the velocity ſought in a contrary direction.

Thus, in the firſt example before ſtated, if we ſuppoſe the bodies to be elaſtic, the velocities, after colliſion, will be 5 and 10, and conſequently the quantities of motion will be 15 and 20.

In the ſecond example, the velocities, after colliſion, will be $1\frac{2}{3}$, and $11\frac{1}{3}$, and the quantities of motion $4\frac{1}{3}$ and $23\frac{1}{3}$.

For a third example, let us ſuppoſe two bodies, in proportion as three to two; the firſt at reſt, and the ſecond moving towards the firſt with 40 degrees of velocity: then will the quantities of motion before the ſtroke be 0 and 80, the common velocity after the ſtroke 16, the quantities of motion after the ſtroke 48 and 32, the quantity of the ſtroke 48, the velocity gained 16, the velocity loſt 24, the velocities after the reſtitution of the ſprings 32, and 8 in a contrary direction; the quantities of motion after colliſion 96 and 16.

In the firſt example, the ſum of the motions before colliſion, is equal to the ſum of the motions after colliſion; in the ſecond it is greater; in the third leſs.

Two elaſtic bodies always recede from each other after colliſion, and that with the ſame relative velocity with which they tended towards each other before colliſion. Thus the relative velocity, before and after colliſion, is 5 in the firſt example, 13 in the ſecond, and 40 in the third.

And in all caſes, whether the impinging bodies are elaſtic or not, the ſum of the motions in the ſame direction, and the difference of the motions in contrary directions, are the ſame both before and after colliſion.

If two equal elaſtic bodies move towards each other with equal velocities, they will recede from each other after colliſion each with the ſame velocity. If one of them, in motion, ſtrike againſt the other at reſt, it will communicate the whole velocity, and remain at reſt itſelf. If one overtakes the other, they will interchange velocities, and continue to go on the ſame way as before. If they meet each other with different velocities, they will interchange velocities, and fly off from each other in contrary directions.

If an elaſtic body ſtrikes upon an immoveable elaſtic obſtacle, it will rebound with the ſame velocity that it came.

If one of the impinging bodies be hard, and the other elaſtic, the laws of the communication of motion are the ſame as if both the bodies were elaſtic; for the ſpring will give way, till the force of elaſticity becomes equal to the force of compreſſion, that is, double to the quantity of the ſtroke in each body; and the re-action of a hard body againſt double the quantity of elaſticity, will produce the ſame effect as a ſingle quantity of elaſticity in each body acting in contrary directions.

If the impulſe is oblique, it muſt be reſolved into two impulſes, one direct, and the other parallel to the tangent at the point of colliſion. The effect of the direct impulſe muſt be computed according to the laws before-mentioned: the parallel impulſe will continue after the colliſion the ſame in the body itſelf, and is therefore continually adding to it's velocity; and ſecondly, becauſe the weight or reſiſtance of the rocket is diminiſhing every inſtant by the diſſipation of the parts as they burn away.

GENERAL OBSERVATIONS ON MOTION.*

If you take only a curſory view of the operations in nature, you muſt be convinced that there is ſomewhere an *inexhauſtible ſource of impulſe*, though undiſcernible by our ſenſes: conſider the diſſolving power of menſtruums, the violence of fire, the ſtrong contraction of our heart and arteries, the ſtability of heavy maſſes held down by the force of gravitation to the earth, the firm coheſion of bodies, and you muſt own all theſe muſt have ſome prodigious fund, though you know not whence to derive the force they exert.

The heavens, the earth, and all the elements are in conſtant motion; the matter of the earth, &c. is conſtantly paſſing into the ſubſtance of trees and plants, and as conſtantly returning from them again in their diſſolution; the ſea is moved with tides and currents; the air is agitated with winds and ſtorms; and light is continually flowing from the ſun, ſtars, &c. to the utmoſt boundaries of the univerſe.

Wherever the ſources of this fund may be, or however copious the ſupplies, they cannot anſwer all the demands made upon them by the conſtant colliſion and other ſources of decay. Every time you clap your hands together, you take ſomething from the ſtock of motion which is to carry on the operations of nature; but the colliſion occaſioned by human actions are very trifles in compariſon with that great quantity of force which is ſpent in the workings of nature. The bearing of rivers againſt their winding banks; the daſhing of ſeas againſt the ſhore; the oppoſition of winds one againſt another, or from mountains; the ſyſtole, or contraction of circulating veſſels in plants and animals; but above all, the gravitation of bodies to earth and ſuns; the coheſion of compounds; the oppoſition of centripetal and centrifugal forces; the various repulſions, &c. which muſt all occaſion every moment an immenſe conſumption of force, and require things to be ſo conſtructed, that there may be continual recruits to ſupply the perpetual diminution.

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* See Jones's Eſſay on the Firſt Principles of Philoſophy.
———— Phyſiological Diſquiſitions, p. 27 & 64.
Tucker's Light of Nature.

We have no knowledge of ſubſtances, or of any being, or of any thing, abſtracted from the *action* of that thing or being.

All our knowledge of things conſiſts in the perception of the power, or force, or manner of acting of that thing; that is, of the action of that thing on our ſenſes, or of the effects of that thing on ſome other thing, whoſe action affects or is the object of our ſenſes, and in the perception of the relations or ratios of theſe actions to each other: for if they produce no alteration on the ſenſes, if no change is perceived by the mind through the medium of the ſenſes, we can have no evidence of their exiſtence; every effect muſt be produced by ſome cauſe or action.

Every thing that you know is an *agent*, or has a power of acting, for you know nothing of any being but it's action, and the effects of that action; the moment it ceaſes to act it is annihilated as to you, you can form no notion of it's exiſtence.

Whatſoever produces any effect or alteration

ſtance are no other than the different actio
action of that thing.

For every property muſt be occaſion
ſome cauſe, and you can have no conception
cauſe without action. The power of *doing*
thing ſeems to be the firſt idea that riſes whe
contemplate real beings; it is that which d
guiſhes them from beings merely poſſib
ideal.

The more you conſider the ſubject, the
you will find it neceſſary to admit of an
agency; for the effects perceived cannot poſſib
the mere effects of compoſition; for *compo*
however exalted or refined, is only the unio
co-arrangement of parts which before were
rated, from which ariſes a certain order and
tion more or leſs perfect, according to the q
and adjuſtment of ſuch conſtituent and inte
elements.

But if ſuch elements be themſelves void
energy, what can mere arrangement generat
various paſſive relations and analogies? If in
dually they poſſeſs neither the power of acti
re-action, of attraction or repulſion, will the
artificial tranſpoſition or co-ordination produ
the compoſite either energy, or motion, or
ance of any kind? To ſuppoſe it, is a ma
abſurdity; it is to ſuppoſe *real energy* can be
rated out of nothing, or out of no antecedent
ject; it is to ſuppoſe a realizing of non-entit
evocation of ſomething out of nothing.

When out of a block of marble the
fal

faſhions a ſtatue of Venus, he adds nothing *internally* to the marble; or when from the fuſed mixture of ſalts and ſand, the moſt beauteous forms re called forth, is any thing more effected than a ew diſpoſition of parts which before exiſted in nother diſpoſition? But in educing active comoſite from inactive elements, not only a new poition takes place, but a real active quality is ſueradded, which did not pre-exiſt in the ſeparate lements.*

Here, however, it is neceſſary for me to enorce upon you one conſideration, that matter acts pon matter not by an *eſſential* but a *mechanical* ower, that is, by it's motion; for in the natural s in the moral world *there is no power but of od.*

Motion is never to be conſidered as a thing y itſelf, but as an *effect*, which like all other effects uſt be referred to their proper cauſes; for the arts of the world have motion not of themſelves, ut as the limbs have by means of their connection ith the body to which they belong.

The parts of every *ſyſtem* have ſome general eference or connection with one ſingle point or art, by which they become a kind of unity or ne ſyſtem. In the animal ſuch connection is eld by means of the nerves, or nervous fluid, or oth, ſo that all parts of the ſyſtem have commuication with the center. Whatever new part is o added as to be united to the common reference, ecomes part of the ſame ſyſtem. Whenever ny part is ſo removed as to have no further refeence to, or communication with the common cenr, it is no longer a part of that ſyſtem.

It is abſurd therefore, in accounting for the henomena of nature, to conſider the motion of any

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* Berrington's Immaterialiſm delineated.

ON PERMANENT MOTIONS IN NATURE. EXTRACTED FROM THE REV. MR. WM. JONES'S PHYSIOLOGICAL DISQUISITIONS.

" The abſurdity of the foregoing principle of Deſcartes will appear more fully by transferring it to a parallel caſe. Thus life is an effect as truly as motion; and as no body can continue to live without the conſtant operation of thoſe cauſes which are acting for the ſupport of life, ſo no inanimate body can continue to move without the proper cauſes of motion. When you are told that bodies are indifferent to reſt or motion, you learn no more than if you were told in other words that they are indifferent to life or death; and if you went on from this principle, to aſſert that a body once moved would move always, unleſs there were ſomething to ſtop it, you would be as much miſtaken as if you ſhould affirm, that the body which lives once will therefore neceſſarily live on till ſomething interpoſes to kill it.

" In accounting for the nature of human life, he would be thought to aſſign a very mean reaſon, that ſhould urge a man lived to-day only becauſe he lived yeſterday; for there are certain phyſical principles on which the animal life is preſerved, and without which it cannot poſſibly ſubſiſt."

In the ſame manner a body continues to move only ſo long as the natural cauſes of motion continue to act upon it, and reſt, which is mechanical death, muſt inevitably follow. Abſolute reſt is abſolute death, the privation of all power, all faculty, all inſtrumentality; it can ſuffer agency, but exerciſe none; it can fill up no place in a chain of being, becauſe incapable of any agency even in the loweſt degree ſubordinate.

iction to ſuppoſe an equal diſpoſition to either to e inherent in any body. Motion is poſitive, implying power or force wherever it acts; reſt is a mere negative, in which body exerts no powers; it weighs, acts, or preſſes neither backward nor forward, up nor down; it produces no effect, and is in the exercise of no power. Notwithſtanding this contrariety between reſt and motion, yet are they confounded together in this law of Deſcartes.

Natural power may be properly defined to be matter actually moving, or exerting a niſus to motion like a ſuſpended weight; but there can be no power where there is no tendency to action; the ſame body cannot therefore at the ſame time be indifferent to the exerting of actual power, and to the exerting none at all.

All natural life, whether animal, mineral, or vegetable, or whatever characterizes matter to our ſenſes, depends upon motion, activity, and power n matter, not on the inherent properties thereof; motion is therefore to be conſidered not as a natural condition of matter, but ſomething ſuperadded thereto, and conſtantly ſupported to conſtitute life, variety, and mutability.

Indeed ſo clear is this opinion, that we find even Dr. Clarke aſſert, "that all the great motions n the world are cauſed by ſome immaterial power perpetually and actually exerting itſelf every moment in every part of the world; and further, that he very laws of motion cannot continue but by omething ſuperior to matter continually exerting n it a certain force or power according to ſuch eterminate laws."

moving in any direction, you may affirm that there is a cauſe acting upon it in the ſame direction; thus if light bodies move outward from an electrified body, we conclude that they are driven by a current of electrified æther, proceeding in right lines from the body. When you ſee the like bodies moving inwards towards the ſphere, you muſt either conclude, as you did before, that there is another flux of matter in a contrary direction to the former, or give up one of the plaineſt principles in philoſophy, that motion is in the direction of it's cauſe. Bodies moving in contrary directions muſt therefore infer cauſes acting in contrary directions.

"As all motion is in the direction of it's cauſe, there can be no ſuch thing as a *power of attraction*; all appearances from whence ſuch a power is inferred muſt neceſſarily be reſolved into impulſe. If the earth attracts a ſtone by a power in the earth, the power exerts itſelf in a direction contrary to that of the effect, and can therefore never happen conſiſtently with the laws of mechaniſm.

"In the motion of different bodies, it is obſervable that ſome retain the motion they have acquired without any diminution, while others are ſoon reduced to a ſtate of reſt.

"When a body maintains it's motion without diminution, it is moved by ſuch a cauſe or cauſes as would renew it's motion if by any means it came to be ſtopped. If you ſtop the motion of the lungs by an effort of the muſcles, the natural cauſes which act upon the body tend to renew their motion, and cannot be eaſily hindered from effecting their purpoſe.

"Every laſting motion is of ſuch a nature that it will be renewed upon it's own principles.

If it were poſſible to ſtop the planet Jupiter in his orbit, or any of his ſatellites, the eſtabliſhed cauſes that act upon them would renew their motion without any artificial impulſe; for impulſion, in the ſenſe it is commonly received, has no more ſhare in any undecaying motion, than in the circulation of the blood in an animal, or the ſap in a vegetable. The heavens are therefore moved by ſuch cauſes as would renew their progreſs if it were poſſible for them to be ſtopped, otherwiſe their motion is not maintained upon phyſical principles. This is not meant as an objection to the ſchemes of motion deduced from the properties of curve lines, becauſe geometrical without phyſical evidence will prove nothing on this ſubject. Motion is to be conſidered as a fact wherever you find it, and muſt be derived from principles agreeable to the general order of nature.

" Nothing can act where it is not, and therefore nothing can communicate it's action to any other thing which is at a diſtance from it, but by the intervention or communication of ſome middle thing or medium which extends from the one thing to the other. We perceive that the ſun communicates ſome kind of action to all the planets, by which they circulate round it, and by which they are retained in their orbits, or gravitate towards it; ſo likewiſe we obſerve that the earth communicates action to bodies at a diſtance from it, by which they gravitate towards the earth: there muſt therefore be ſome medium, ſome middle thing, by which the ſun and the earth communicate action to other things at a diſtance from them.

" That two diſtant bodies both ſuppoſed at reſt ſhould be able to act upon one another without the aſſiſtance of any third ſubſtance, is to inveſt matter with a power of beginning motion itſelf, which is making motion eſſential to matter, and on this the materialiſt builds his ſyſtem; it is a notion which the French ſoi-diſant philoſophers have turned to the purpoſes of atheiſm. Nor need you have recourſe to ſuch a principle, for every thing proves to you that there is active* matter preſent where it is neither ſeen nor felt, as fire, air, elaſticity, &c. and all the phenomena that ſurround you evince the continuity of material agency.

"All the experiments made upon the elements, which are the moſt uſeful experiments for advancing phyſical knowledge, tend to ſhew how matter interpoſes to produce ſuch changes and motions as we obſerve in bodies diſtant from each other. How does the ſun act upon the fruits of the earth, but by the mediation of it's light? How do the clouds water the earth, but by the mediation of air? How does the chemiſt produce ſo many changes, but by the mediation of fire? In ſhort, wherever diſtant bodies affect each other, there is always ſomething to mediate, whether it is or is not viſible; and when this mediation can be traced no further, *natural* philoſophy terminates. Amuſe not therefore yourſelves with names and qualities which contradict the known laws of mechaniſm, and ſuperſede the operation of the elements.

"In order to account for the laſting motion of the heavenly bodies, it is moſt agreeable to analogy, reaſon, and obſervation, to admit a general principle of circulation in all fluid matter, which circulation certainly prevails in ſuch parts of nature as are more immediately ſubjected to examination, and may with propriety be extended to the un itſelf, and the elementary matter in the celeſial ſpaces.

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* Not active by it's own nature, but according to the mechaniſm of the world.

"It has been a queſtion in philoſophy, wheher bodies can move in a ſpace which is filled with matter commonly called a plenum? But this queſion cannot be anſwered without firſt conſidering he condition of the matter, and ſtating the circumſtances of the moving body.

"If the matter ſo filling any ſpace is in a fluid condition, ſo that the parts can ſlide freely over one another, they will be able to move in different or even contrary directions at the ſame time; and while the place of the whole maſs continues the ſame, the place of the parts which compoſe it may change every moment.

"The fulneſs of the ſpace is therefore no objection to a free motion of the parts of fluids among themſelves, neither is it an objection to the motion of any ſolid body in ſuch a fluid medium.

"If a veſſel be filled with water and cloſely ſtopped, any ſolid body that floats therein will move freely from one ſide to the other, or from the top to the bottom, becauſe the parts of a fluid which are diſplaced before fall into the ſpace behind as the body leaves it; ſo faſt as the body proceeds, juſt ſo faſt do the parts of the fluid recede, without finding impediment or vacuity. Again, there may be fulneſs of matter and yet there may be motion, provided there is a circulation among the parts of the medium.

"It is eaſy to foreſee what will happen to any ſolid body moving in a fluid medium, by attending to the circumſtances. When the body is moved by any artificial force or effort of violence, contrary to the nature of the medium in which it moves, the parts of the medium in recovering their natural ſtate will reſiſt the motion of the body till the equilibrium is reſtored, and the body is at reſt.

"But if the motion of the body ariſes from the motion of the medium, then the reſiſting nature of the medium is no longer any objection to the motion of the body; for it is abſurd to imagine, that the cauſe of motion can reſiſt the motion which it cauſes.

"No inferences from the reſiſtance of mediums can lead us to the neceſſity of a *vacuum*. A vacuum can only be wanted when a motion is propoſed which is independent of the action of every medium; but there is no ſuch motion in nature; on the contrary, we every where find examples of an unreſiſted motion, from impelling fluids in reſiſting mediums."

"At the extremities of the ſteel rod are two ſmall lamps, over the lamps are two vanes of braſs placed with contrary aſpects, and inclined at an angle of about 45°; the rod is ſuſpended on a point, ſo that the whole will turn freely. As ſoon as the lamps are lighted, the machine you ſee begins to turn freely upon it's center; it now makes ſeveral revolutions in a minute, and will continue thus to move ſo long as the lights continue burning; and ſuppoſing the lights to have a continual ſupply, the conſequence would be a perpetual motion in the machine.

"Air is a reſiſting medium; yet inſtead of retarding the motion of the machine by it's reſiſtance, it preſerves that motion by it's impulſe; and though the motion diſcontinues at laſt, it is not owing to any defect or irregularity in the *cauſe* but by the imperfection of the materials; if theſe would but continue in the ſame ſtate, the motion would be unretarded ſo long as air and fire, which are the cauſes of it, ſubſiſt in the world. The cauſes of motion are not artificial, but ſuch as are ſupported by nature itſelf in it's regular mode of acting; theſe begin and continue the motion.

" Thus you ſee if a fluid act as an impelling cauſe to a moving body, it's reſiſtance with reſpect to the ſame body becomes of no account; it is in a manner annihilated without removing a ſingle particle of matter. The like is true of all floating bodies; when the motion of the fluid conſpires with the motion of the body, the body moves with the velocity of the fluid, and loſes nothing by communication. In fluids which have a motion of their own, bodies under proper circumſtances will not loſe motion, but acquire it. If the matter of the heavens has a motion of it's own, the planets will thence derive their revolutions, inſtead of being retarded thereby.

" In all theſe experiments, where there can be no reaſonable doubt about the explanation, matter is found to act upon other matter for producing the effect; and we are able to trace this in ſuch a variety of inſtances, that unleſs the world is governed by oppoſite and contradictory principles, the ſame rule muſt obtain throughout the whole.

" The body of man, which is the higheſt piece of machinery in nature, is made to *ſee*, *hear*, and *ſpeak*, upon mechanical principles; and it dies without the conſtant impreſſion of a material force upon it from the element of *air*. By the preſſure of the atmoſphere, the mercury is made to riſe in the tube of a barometer; hail, ſnow, and vapours are formed therein by it's different temperatures; clouds are ſuſtained by and driven about in it; plants grow and are nouriſhed by it; and for thoſe effects, rects the well-meaning ignorance of thoſe modern philoſophers, who would confute atheiſm by leaving out ſecond cauſes; and at the ſame time leaves us in poſſeſſion of that ancient and valuable doctrine, that ſome of the elements are appointed to rule over and govern the reſt."

LECTURE XXXI.

Of the Mechanical Powers.

THE knowledge of mechanics is one of thoſe
things that contribute to diſtinguiſh civilized
tions from barbarians. From it the works of art
rive much of their beauty and value; without it
can make very little progreſs in the knowledge
the works of nature. By this ſcience we are
abled to improve every power and force in na-
re, and render the motions of the elements water,
r, and fire, ſubſervient to the purpoſes of life.

A weight greater than the natural ſtrength of
an could manage, without ſome mechanical con-
ivance, could never be lifted from the earth: he
obliged, therefore, to ſeek aſſiſtance, and call in
her forces, to make ſuch alterations as his plea-
res or neceſſities may require. By means of
vers he lifts weights much greater than his
ength could overcome; with the wheel and axle,
llies, &c. he lifts them to conſiderable heights,
d produces ſuch effects, as would, to an unex-
rienced ſavage, appear the work of enchant-
nt.

Nor were the ancients without a great know-
lge in this art of increaſing ſtrength by ma-
inery. The ſtones which are laid upon the tops
the pyramids of Egypt, each of which is as big
a ſmall houſe, create even the wonder of a mo-
rn mechanic, and teach him to reverence the
perior arts of antiquity.

Practical mechanics will ſhew you how to employ a given force, ſo as to produce a propoſed effect by the aid of ſome machine or engine. It alſo ſhews how to modify by machines the action of a given power, or the quantity of a known effect.

Three things are therefore always conſidered in treating of the mechanical engines; a *weight* to be raiſed, the *power* by which it is to be raiſed, and the *inſtrument*, or engine, by which it is to be effected.

Mechanics may be conſequently reduced to two problems: 1. To determine the proportion which the power and weight ought to have to each other, that they may juſt ſuſtain each other in equilibrio. 2. To determine what ought to be the proportion of the power and weight to each other in a given engine, that it may produce the greateſt effect in a given time.

Machines, or engines, may be conſidered as different means employed to facilitate the action of a power againſt a reſiſting obſtacle.

The number and nature of mechanical engines, vary according to the object for which they are deſigned; but, however varied or multiplied, you will find them to be only a combination of a ſmall number of ſimple machines, commonly called *mechanical powers.*

I ſhall conſider ſix ſimple machines; the *lever*, the *pulley*, the *wheel and axis*, the *inclined plane*, the *wedge*, and the *ſcrew*.

Theſe are all calculated to communicate motion to bodies, and ſuſtain a preſſure, for which the power, unaſſiſted by them, is incompetent; and the artifice in all conſiſts in diſtributing the weight among ſuch a number of agents, that the part ſuſtained by the power may bear a ſmall ratio to the whole.

Thus, a power incapable of communicating
notion to, or ſupporting the preſſure of a body,
rithout mechanical aſſiſtance, may effect it's pur-
ofe by tranferring a part of the weight upon the
pport, or fulcrum, diſtributing it among a num-
er of pullies, or placing it upon an inclined plane,
r ſcrew.

POSTULATA.

The following poſtulata are neceſſary for the
athematical conſideration of the mechanical
owers.

1. That a ſmall portion of the earth's ſurface
ay be conſidered as a plane.

2. That heavy bodies deſcend in lines that
e parallel to each other: for though all bodies
nd to the center of the earth, yet the diſtance
om which they fall is ſo ſmall, when compared to
eir diſtance from the center of the earth, that
eir inclination is inconſiderable.

3. That the effort of any given power, or weight,
the ſame in all points of it's direction; or if a
dy be acted on by any power in a given direc-
on, the action will be the ſame, in whatever part
that direction it be applied.

4. That though all matter be rough, all ma-
ines imperfect, &c. yet, in order to make calcu-
ions more eaſy and elegant, and to render theory
re perfect, we ſuppoſe all planes perfectly even,
bodies quite ſmooth, all lines ſtrait and in-
ible, without weight, and without thickneſs,
cords to be extremely pliable, and all machines
hout friction.

Theſe ſuppoſitions go no further than to ſhew,
t the reaſonings are concerning perfect inſtru-
nts; but as there are none really ſo, the dif-
nce between theory and practice is to be after-

wards inveſtigated, and, when diſcovered, allowed for.

5. *The effort of the power, and of the weight, is equal in all points of their directions;* i. e. if you puſh or draw any body with a ſtick (ſuppoſed inflexible, and without gravity), this body is puſhed or drawn with the ſame force, whether the ſtick be long or ſhort. Or if a weight be ſuſpended by a long or ſhort ſtring, it will neither weigh more or leſs, the weight of the ſtring excepted; for though gravity varies according to the different diſtances of a body from the earth, this variation is totally inſenſible in the length of a cord by which a weight is ſuſpended from a machine.

Here it may be proper to recall to your mind what I have before ſhewed you, that the *momentum* of any power or weight, is that force wherewith it either moves, or endeavours to move; and that it is always proportional to the product ariſing by multiplying the power or weight into the velocity wherewith it moves, or would move, if it were not hindered by ſome oppoſite power or weight. If the product ariſing from the multiplication of one weight or power into it's velocity, be equal to the product ariſing from the like multiplication of any other weight or power into it's velocity, *the momenta of thoſe two powers or weights muſt be equal.* And this will always happen when the weights or powers are to each other reciprocally as their velocities.

Hence two weights or powers will ballance, when the one exceeds the other in weight, as much as it ſurpaſſes the other in velocity; and herein conſiſts the force and efficacy of mechanical engines; for they are ſo contrived, as to diminiſh the velocity of one weight or power, and to increaſe that of the other; by which means a very ſmall weight or power may ballance a very large one.

In general, therefore, there is always an equilibrium, when the ſum of any number of acting powers is equal, and directly oppoſed to any one power, or to the ſum of the forces of any number of powers; and reciprocally, if there be an equilibrium among the acting powers, the ſum of the acting powers on one ſide, are equal to the ſum of the powers acting on the oppoſite ſide.

Effects are always in proportion to their adequate cauſe; or the change of motion, in any body, is always in proportion to the force which produced it, and in the direction wherein that force acts: for inſtance, if a certain force affects a certain motion, double that force will occaſion double that motion.

It follows, from this axiom, that if an effect depends on ſeveral heterogeneous cauſes, or if ſeveral different circumſtances concur in producing any effect, this effect will be as the quotient reſulting from dividing the product of the circumſtances that contribute to augment the effect, by the product of thoſe that concur to diminiſh it.*

Or, in other words, an effect produced by ſeveral diſſimilar cauſes, is in a ratio compounded of the direct ratio of the quantities which muſt be increaſed in order to augment the effect, and the inverſe ratio of thoſe that muſt be diminiſhed to increaſe the effect.

To illuſtrate this by an example, ſuppoſe a waggon to be ſent to any particular place; it is clear that the facility of conveying it, or effect, depends on the weight, the number of horſes employed, the ſtrength of the horſes, length of the way, goodneſs of the road, and time to be employed.

Now it is eaſy to ſee, that the facility of moving

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* De la Caille's Elements de Mechanique, p. 5.

moving the waggon will increaſe, in proportio as the number of horſes, their ſtrength, the goodneſs of the road, and the time, are increaſed, an the weight of the load, and length of the way, diminiſh.

Six things are to be conſidered in mechanica powers: 1. The power. 2. The reſiſtance. 3 The fulcrum, or ſupport. 4. The velocity of th power and reſiſtance. 5. The center of gravity 6. The line of direction.

OF THE LEVER.

The lever is an engine, which, when treated mathematically, is conſidered as an inflexible line, void of all gravity; though in practice it is a ſolid bar, that is flexible and weighty.

In the lever, you will more particularly direct your attention to three circumſtances: 1. The fulcrum or prop by which it is ſupported, or axis about which it turns. 2. The power to raiſe and ſupport the weight. 3. The reſiſtance or weight to be raiſed or ſuſtained.

The axis of a lever is the point about which it turns.

The points of ſuſpenſion are thoſe points where the weights really are, or from which they hang freely.

The weights are always ſuppoſed to act at right angles to the lever, except it is otherwiſe expreſſed.

As the lever is generally applied to lift or ſuſtain weights, by means of a power, and fulcrum, or prop, it has taken different names, from a difference in their relative ſituations.

It is called a lever of the *firſt* kind, when the fulcrum is between the power and the weight.

When you ſtir the fire with a poker, you make

uſe

ſe of this lever. The poker is the lever; it reſts pon one of the bars of the grate as a fulcrum; the icumbent fire is the weight to be overcome, and ie hand at the other end is the power.

In the *ſecond* kind of lever, the weight is laced between the fulcrum and the power.

Thus, in raiſing a water-plug, &c. the worknan puts his iron lever through the hole in the lug, till he reaches the ground on the other ſide; nd making that his fulcrum, lifts the plug by his trength applied at the other end of the lever.

In the *third* kind of lever, the power is ſituted between the weight and the fulcrum. The wo above-mentioned levers aſſiſt the ſtrength, but vith the third kind the workman acts at a diſadantage; as in raiſing a piece of timber, or ladder, ip on one end. In this the man's ſtrength, or ower, is in the middle, the part of the ladder aleady raiſed is the weight, and the end upon the ground is the fulcrum.

There will be an equilibrium on a ſtrait lever f any kind, when the power is to the weight, as the iſtance of the weight from the fulcrum is to the diſance of the power from the fulcrum.

For it is evident, that there is always an equiibrium between equal and oppoſite forces; but orces are equal when the velocities of the weight re inverſely as the quantities of matter, but the liſtances of the weight and power from the fulrum will expreſs their velocities, becauſe theſe iſtances may be conſidered as the radii of arcs hat they would deſcribe in the ſame time, and heſe arcs are to each other as their radii, and conequently the velocity of each point of a lever will e as the diſtance of it from the center of motion. herefore, as on the preſent hypotheſis the veloities are inverſely as the maſſes, and the forces act in oppoſite directions, they are conſequently in equilibrio.

Or the propoſition may be proved thus: if there be not an equilibrium, let one of the weights preponderate. The preponderating weight has therefore more momentum than the other; but ſince, by the hypotheſis, the weights are inverſely as the arms of the lever, it follows, that the velocities of the weights are inverſely as their quantities of matter, whence the moments of both are equal; but they were proved unequal. This contradictory concluſion reſults from denying the propoſition affirmed, which is therefore true.

To eſtimate, then, the advantage of a power over a reſiſtance, it is only neceſſary to determine what force will maintain an equilibrium between them; for if their power be increaſed, it will overcome and raiſe the weight.

From hence, then, we may deduce,

1. That a power acts more efficaciouſly againſt a weight, in proportion as the power is more diſtant from the fulcrum.

2. That two equal maſſes, acting in oppoſite directions on the ſame lever, cannot be in equilibrium but when they are equally diſtant from the fulcrum.

3. That two unequal weights exert equal forces, when the diſtance of the ſmall weight from the fulcrum exceeds the diſtance of the large weight from the ſame, as much as the large weight exceeds the ſmall one; or, in other words, when the diſtances from this fulcrum are reciprocally as their maſſes.

Theſe propoſitions are alſo demonſtrated by the following experiments.

In making experiments on the mechanic powers, ſome difficulties ariſe from the weight of the materials ; but as it is impoſſible to find any t are without weight, we take care that the ers, &c. are perfectly ballanced themſelves, be- e the weights and powers are applied, as they uld otherwiſe alter the proportion between the wer and weight; but being ballanced, the effect not influenced by the weight of the materials.

The bar, therefore, uſed in making the expe- nents on levers, has the ſhort end ſo much thicker an the longer arm, as will be ſufficient to bal- nce it on the prop; the hooks are all at equal ſtances from each other.

Of the lever of the firſt kind. Before you is a er, A B C, *fig.* 1, *pl.* 3, of the firſt kind, turn- g on an axis, D, which is the fulcrum that ſup- rts it. The parts A B, B C, on different ſides of e prop, are called the *arms* of the lever. The orter arm is made ſo thick and heavy, as juſt to llance the longer arm: thus the lever is reduced an horizontal poſition; and being in equilibrio th itſelf, may be conſidered as without weight. he longer arm is divided into ſix equal parts: e diſtance of the hook from the fulcrum of the orter arm, is exactly equal to one of theſe parts; that the whole lever may be conſidered as di- ded into ſeven equal parts.

Now, from the propoſition juſt explained to ou, it is clear, that the power gained by this ver, or added to the natural ſtrength or force of e agent, is increaſed in proportion as the one m, as B C, is longer than the other A B. The elocities of the different parts of the bar, are as e diſtances of thoſe parts from the fulcrum.

To illuſtrate this by experiment, ſuſpend on e longer arm a weight of one ounce, at the xth hook from the fulcrum, and hang a weight f ſix ounces on the hook of the ſhorter arm, and e weight of one ounce will juſt ballance and ſupport the weight of ſix ounces. The weight of one ounce may be called the power, and that of ſix ounces the reſiſtance or weight. The reſiſtance is as much nearer to the fulcrum, as the power is lighter than the reſiſtance. A man, therefore, who can without the help of any machine ſupport one hundred weight, will be enabled by this lever to ſupport ſix hundred.

As in this lever, the fulcrum may be placed exactly at an equal diſtance from the power and weight, or nearer to the one than the other, it is clear, that the power and weight may counterballance each other when they are equal, or when the one exceeds, or is exceeded by the other, according to the different ſituations of the fulcrum.

Of the hammer lever. This lever differs in nothing but it's form from a lever of the firſt kind. It's name is derived from it's uſe, that of drawing a nail out of wood by a hammer.

Suppoſe the ſhaft of a hammer to be five times as long as the iron part which draws the nail, the lower part reſting on the board as a fulcrum; then by pulling backwards the end of the ſhaft, a man will draw a nail with one-fifth part of the power that he muſt uſe to pull it out with pincers; in which caſe the nail would move as faſt as his hand, but with the hammer the hand moves five times as much as the nail, by the time that the nail is drawn out.

To confirm this, in our apparatus, *fig.* 2, *pl.* 4, and *fig.* 2, *pl.* 5, we have a lever whoſe arms, A B, B C, are at right angles to each other. The heel turns on a pin, B, as the fixed axis. Hang a weight of five ounces on the ſhorter arm, then hang a weight on the fifth diviſion of the longer arm, by means of a ſtring going over the pulley in the frame oppoſite to it, and theſe weights will ballance each other.

It may be proper to obſerve, that though weights will be at reſt when they are in equilibrio, yet it is not abſurd to reaſon concerning their velocity, and to ſay that they are in equilibrio, becauſe they are to each other as their reſpective velocities: for here we do not mean the velocities with which the power and weight move, that indeed might be abſurd, as neither of them move at all; but we mean the velocity with which they muſt begin to move, if they were to move. When, therefore, in giving a reaſon for an equilibrium, we ſay that the power and weight are to each other as their reſpective velocities reciprocally, we do not mean the velocity with which the power and weight move, but the velocities with which they muſt begin to move, if they were to move. Thus, if the center of motion divide a lever of the firſt kind in the proportion of one to ſix, a power of a hundred pounds, applied at the end of the long arm of the lever, will be in equilibrio with a weight of ſix hundred pounds, ſuſpended at the end of the ſhorter. And when we ſay that the power and weight are to each other as their reſpective velocities reciprocally, we mean that the weight cannot begin to move without making the power move with ſix times it's own velocity; ſo that the weight cannot move in one direction, unleſs it can make the power move in a contrary direction, with a momentum equal to it's own; and as equal forces, acting in contrary directions, deſtroy each other, they will remain in equilibrio.

Of the ſecond kind of lever. In this kind the weight is between the fulcrum and the power.

Thus the bar A B C, *fig.* 2, *pl.* 3, is ſupported on the table D, at the end A. The *weight* E is hung any where upon the bar, as at B; and the power, or hand, is applied at the other end, C, of the bar, to lift up that end, and raiſe the weight.

The power or advantage gained by this lever, is as great as the diſtance of the hand from the table or prop D, exceeds the diſtance of the weight from it. Thus, if the power, or hand, C, be ſeven times as far from D as the point B, on which the weight E is hung, a power equal to one-ſeventh part of the weight will ſupport it; ſo that here, as in the preceding caſe, the *power* is increaſed in proportion as it's diſtance from the fulcrum exceeds the diſtance of the weight from the fulcrum.

To confirm this by experiment, faſten a hook to the fifth hook of the longer arm of the lever A B C, fixed at H I, *fig.* 2, *pl.* 4, and carry it over the pulley placed directly over it; ſuſpend a weight of one ounce from the end of the ſtring, and this will ballance a weight of five ounces ſuſpended from the firſt hook from the fulcrum; ſo that a man taking hold of the bar at C, and pulling upwards, could ſupport five times more weight hanging from the point D, than he could ſupport without the lever; but the end of the bar muſt be raiſed five inches, in order to raiſe the weight one inch.

The ſtring is put over the pulley, in order that the power may act in a contrary direction to the weight. There is a ſlit in the bar over the lever, that the pulley may be placed over any part thereof. When uſed, it ſhould be ſo placed, that the ſtring going over it be perpendicular to the lever, the lever being in an horizontal ſituation.

Of the third kind of lever. In this machine the power is between the fulcrum and the weight: it may be conſidered as the ſecond kind reverſed for the *power* in this *muſt exceed the weight,*

weight, as much as the diſtance of the latter from he fulcrum, exceeds that of the power from the ulcrum.

If you place the end A, of the lever A B C, *fig.* 3, *pl.* 3, under the table, and divide the bar nto ſeven equal parts from A to C, and ſuſpend a weight of one ounce at the end C; then a hand placed at B, one diviſion from the fulcrum, muſt pull up with a force equal to ſeven ounces, to ſupport the weight C of one ounce; and if the hand riſes one inch, the weight will be raiſed ſeven inches.

To illuſtrate this by experiment, fix one end of a ſtring to the firſt hook of the lever A B C, *fig.* 2, *pl.* 5, and bring it over the pulley D, which for this purpoſe you muſt now place over this hook, and to the other end of the ſtring hang a weight of five ounces, which acts as a power to pull the lever upwards. This will be counterpoiſed by a weight of one ounce at the fifth hook. No mechanical advantage is gained by this lever, becauſe the power here muſt exceed the reſiſtance, as much as it's diſtance is nearer the fulcrum than that of the reſiſtance; it is therefore ſeldom uſed.

If you examine the inſtruments in general uſe, you will find that moſt of them are levers of one or the other denomination. Thus, this pair of pincers is made up of two levers of the firſt kind, whoſe center of motion is the rivet. The power is applied at the handles to preſs them together, and thereby pinch the body, as a weight, at the oppoſite ends. In this caſe, if the diſtance of the power, in both levers, is triple to that of the weight from the rivet, the power acts ſix times ſtronger on the weight, than if it were applied directly to it.

A pair of *ſciſſars* is alſo made up of two ſuch levers. In theſe it is clear, from what has been ſaid, *weight.* In other words, when two powers ſupport a weight by the help of a lever, the ſum of the powers muſt be equal to the weight; and the weight being placed between them, their reſpective diſtances therefrom muſt be reciprocally as the powers.

To illuſtrate this, I ſhall ſuſpend this divided beam from the points 4 and 3, by weights going over the pullies in the bar above the beam; these weights being to each other reciprocally as the diſtances from the point o, where the reſiſtance is to be ſuſpended, and will be in equilibrio with ſeven ounces, ſuſpended from the point o of the beam.

Upon this principle, horſes of unequal ſtrength may be made to draw equally in a coach; for by dividing the ſpring bar unequally, that horſe muſt apply more ſtrength than is applied to the ſhort end of the bar. Two men alſo, who carry a barrel hanging from a ſtaff, are unequally preſſed upon their ſhoulders; if the barrel does not hang in the middle, that man carrying moſt who is neareſt.

If at one end of a lever be fixed a weight, which, moving with the end of the lever, does not hang freely, while the power acting at the other end is a heavy body hanging freely, or an inanimate power preſſing perpendicularly towards the earth, ſuch a fixed weight would vary in force according to the poſition of the beam. The force will alſo vary, according as the center of gravity of the weight is above or below the beam.

When the center of gravity of the fixed weight is *below*, the beam (as in *fig.* 7, *pl.* 5,) will become heavier, or act more ſtrongly, when raiſed above the horizontal line, by inclining the lever; and lighteſt when below the horizontal line, when the lever is inclined contrary to it's former ſituation.

But, on the contrary, if the center of gravity f the fixed weight be *above* the beam, (as in *fig.* 8, l. 5,) it will be heavieſt when depreſſed below the orizontal line, and becomes higheſt when raiſed bove the horizontal line.

But the fixed weight will act in the ſame nanner as if it hung freely, when the lever is in n horizontal ſituation.

When the lever, with the weight C faſtened bove it, is in an horizontal poſition, the line of irection is c p, and p is the point on which the enter of gravity acts. When the lever is in the oſition S O M, the point e, through which the line f direction paſſes, is nearer the lower end c of the ever than p. When the lever is in the poſition T O R, the point a, through which the line of direcion paſſes, is nearer the center of the lever. It is herefore evident, from a bare inſpection of the igure, 1. That when a fixed weight, whoſe center of ravity is *above* the lever, is below the horizontal ine, the point of action gets further from the center f motion, and it's momentum, or effect, is *increaſed.* . That when it is above the horizontal line, the oint of action approaches nearer the center of notion, and the momentum, or effect of the weight, *diminiſhed.*

When the center of gravity of the fixed eight is *below* the lever, p is the point of action hen the lever is horizontal; but by inclining it the poſition K R, i c becomes the line of direcon, and i the acting point, which will be nearer o than the point p. By inclining it in the conary direction, c e will become the line of direcon, and e the acting point, farther from o than e point p. Conſequently, when a fixed weight, hich has it's center of gravity below a lever, is neath the horizontal level, the point of action ts nearer the center of motion, and the effect of it's weight is *diminiſhed*; but when the weight is above the horizontal level, the point of action is removed farther from the center of motion, and the effect of the weight is increaſed.

Nothing of this kind will happen when the weight is freely ſuſpended by a rope; becauſe the point of ſuſpenſion, or point of action, is not altered. What has been here proved, concerning levers of the firſt kind, is equally applicable to the other two kinds.

When two draymen carry a barrel on a coulſtaff, to which it is ſuſpended by a chain, the point on which the weight acts is not altered by inclining the ſtaff in going up or down hill; there will be no inconvenience ſuffered, or advantage gained, by the firſt or laſt man: but if they carry the barrel upon two dogs, then the weight does not ſwing, and the center of gravity is below the lever; therefore the point on which the weight acts, will, by inclining the lever, be made to approach the higher end; and the firſt man, in going down hill, by having this point removed from him, will be eaſed in part of his burden, and the laſt man will have his equally increaſed. When two chairmen are going down hill, if the center of gravity of the weight they carry is above the plane of the poles, the man that walks firſt will have the diſadvantage: if it be below the plane of the poles, the man that walks laſt will have the diſadvantage: but if the center of gravity is in the plane of the poles, the action will be equally divided in going down hill.

To ſhew that a power is moſt effectual when it acts at right angles. Unhook the ſcales from the braſs beam G H I, *fig.* 2. *pl.* 4, and raiſe the tranſverſe arm M N ſo as to be only a few inches diſtant from the beam; and place two pullies, ſo that their outer edge may be exactly three inches diſtant from

2 the

: point where the ſtring falls, by which a weight four ounces hangs freely from the beam. This ll be ballanced by a weight of four ounces, at an ual diſtance, on the oppoſite arm of the beam. ıt if you put the ſtring over either of the pul- :s, by which means the weight affixed thereto ts obliquely on the beam, it is over-ballanced by e equal weight on the oppoſite arm; and ſo much , that, in the preſent inſtance, it requires one ınce additional weight to make it counterpoiſe e other.

The quantity of motion produced by a power hich acts upon a lever is always proportional to the ving force.

We ſay, indeed, that the weight a man is liged to lift, by the help of a lever, is greater ın his ſtrength; but by this we mean only that : weight is greater than he could raiſe by his ength directly applied to it, in ſuch a manner as make his power, and the weight that is to be :ed, move with the ſame velocity.

He is enabled to raiſe it by the help of a lever, :auſe, by ſuſpending the weight at the ſhorter d of the lever, and applying his ſtrength at the ıger arm, the weight is made to move ſlower ın the power. And though the momentum of : weight, when it moves with the ſame velocity the power, may be greater than his ſtrength, : the proportion which the velocity of the weight ars to that of the power, may, by means of the 'er, be diminiſhed till the moving force which exerts ſhall be equal to the momentum of the :ight.

No motion is therefore produced by the lever elf: the only uſe of it is to make the weight ve ſlower than the power; ſo that, by means of : mechanical inſtrument, we can indeed lift a greater weight than we can without it, but at the ſame time we only produce the ſame quantity of motion, for as much as the momentum we can raiſe with a lever exceeds it's weight, ſo much it falls ſhort in velocity of the momentum we could raiſe without one. This reaſoning is applicable to all the other mechanical powers.

MECHANICAL ARITHMETIC.

Several weights ſuſpended at different diſtances from the axis on one ſide of a ballance, will counterpoiſe ſeveral others ſuſpended at different diſtances on the other ſide; provided the product ariſing from the multiplication of the weights on one ſide, by their reſpective diſtances from the axis, be equal to the ſum ariſing from the like multiplication of the weights on the other ſide into their reſpective diſtances.

Thus ſuſpend a weight of one ounce at two inches diſtance from the axis of the beam, *fig.* 2, *pl.* 4; another of two ounces, at three inches; and a third of three ounces, at four inches: and if on the other ſide you ſuſpend one weight of five ounces at one inch from the axis, and another of three ounces at five inches diſtance, the two latter will ballance the three former; for the product of five inches to one, added to the product of three by five, gives twenty equal the product of one into two, added to that of two into three, and three into four.

From this principle you may eaſily deduce a method of finding the center of motion, about which when equal or unequal weights are ſuſpended at the ends of a ballance of known length and weight, they will be in equilibrio.

From hence you will perceive how eaſy it is to perform what is called *mechanical arithmetic*, by means of a divided beam and a proper ſet of weights.

Addition. Let the numbers to be added be 2, 3, and 7. I apply an ounce weight at the ſecond diviſion, and another on the ſame arm at the third; I now take an ounce weight, and move it along the other arm till the beam is in equilibrio, which I find to be the caſe when the weight is at the twelfth diviſion.

Subtraction. To ſubtract five from twelve. Hang an ounce weight at one end of the arm at twelve inches, and another at the other end at five; then move a third ounce weight along the arm till the equilibrium is reſtored, and you will find it to be at the difference ſeven.

Multiplication. Multiply four by three. Suſpend a four ounce weight at the third diviſion on one arm, and move an ounce weight on the other till the beam is in equilibrio, and you will then find it mark out the product twelve.

Diviſion. To divide twelve by four, ſuſpend an ounce at the twelfth diviſion, and move a four ounce weight on the other arm till there is an equilibrium, and you will find it at the quotient three.

OF THE BALLANCE.

The ballance, as you all know, is an inſtrument of very extenſive uſe, being applied to eſtimate the weights of bodies, that is, to compare the weight of any given ſubſtance with certain ſtandard weights previouſly determined.

The ballance is a lever of the firſt kind, whoſe arms are of an equal length; in other words, the points from which the weights are ſuſpended, are equally diſtant from the center of motion. In treating of a ballance four parts are principally to be conſidered: 1. The beam itſelf. 2. The center of motion. 3. The arms of the beam. 4. The points of ſuſpenſion.

To conceive more clearly the principles of the ballance, it is conſidered theoretically as an inflexible mathematical line; a point in the middle of the line repreſents the fulcrum, and the nearer the ballance in practice can be brought to this abſtracted view of it, the more perfect is the conſtruction thereof. From this view, you muſt clearly ſee, that points equally diſtant from the fulcrum or center of motion, will deſcribe equal arcs; if therefore equal weights be freely ſuſpended at equal diſtances therefrom, their moments will be equal, and the beam will be in equilibrio. For ſince all bodies tend towards the earth with forces proportional to their weights, if two weights are equal their efforts are equal; and if they are ſuſpended from the extremities of a lever, whoſe arms are equal, they act with equal power on each arm, and conſequently one does not tend more to the center of the earth than the other; therefore if the fulcrum is immoveable, the two extremities will be ſo likewiſe, and remain equally diſtant from the center of the earth or parallel to the horizon. It follows alſo, that the further the points of ſuſpenſion are from the center, or the longer the beam, the more the momentum of the weights is increaſed, and conſequently the ballance is rendered more ſenſible.

In practice, the beam of a ballance is a ſolid bar, and is made of the moſt homogeneous and inflexible materials, and is proportioned in ſtrength to the weight it is intended to ſupport; for if the beam be too weak, or loaded too much, the arms will bend, which will render the beam leſs ſenſible, and if the arms bend unequally, will make it untrue.

The arms ſhould be accurately of the ſame length, and as long as poſſible, relative to their thickneſs and the weight they are intended to ſupport.

If the bearing edge of the axis is very obtuſe, the diſtance of the extremities of the ballance relative to the fulcrum will be altered.

The two pivots which form the axis or fulcrum, ſhould be in a right line, and at right angles to the beam.

The axis ſhould be well poliſhed and very hard, and it's ſupporting part ſhould be thin, and yet not ſo ſharp as to cut, but a little rounded to avoid friction; theſe edges are firſt made ſharp, and then rounded with a fine hone or piece of buff-leather, which cauſes a ſufficient bluntneſs or rolling edge.

The edge of the axis muſt be more or leſs blunt in proportion to the weight it is to ſupport.

The axis ſhould be at right angles to a plane ſuppoſed to paſs through the middle of a beam.

The rings, or the piece on which the axis bears, ſhould be hard and well poliſhed, parallel to each other in order to prevent friction, and of an oval figure, that the axis may keep it's proper bearing, or always remain at the loweſt point.

The index is a ſlender bar perpendicular to the length of the beam.

Particular care ſhould be taken that the points of ſuſpenſion on which the ſcales hang are in the ſame line with the center of motion, for if the points of ſuſpenſion are higher than the axis, the ballance will vibrate too much.

If they are below the axis, the vibration will be too ſlow; and in either caſe, if the beam inclines, it will divide an horizontal line paſſing through the fulcrum into unequal parts, and therefore deſtroy the equilibrium, though equal weights may be in the ſcales.

The index placed perpendicularly to the beam in order to aſcertain when it is horizontal, would add to the weight of the deſcending arm, and ſo deſtroy the equilibrium, if it were not corrected by a weight placed on the oppoſite ſide of the beam.

As the horizontal poſition of the beam is the only one by which we can well judge of the weight of bodies, particular care is to be taken of the poſition of the fulcrum or center of motion, for you will find that the ſituation of this part alters in a degree the neceſſary perfections of the ballance. There are three ſituations to be conſidered, whether, 1ſt, The center of motion ſhould coincide with the center of gravity of the beam. 2d, Whether it ſhould be above; or 3dly, Below it.

1. When the axis of motion or fulcrum paſſes through the center of gravity, the beam will reſt in any poſition whatſoever, whether the ſcales were on or off, with or without weights.

A beam, where the centers of motion and gravity are coincident, can have no other tendency to an horizontal ſituation but what it may derive from it's own weight, and will therefore turn with the ſame additional weight, whatever may be the weight applied, except ſo far as a greater load produces a greater friction.

If two weights were ſuſpended from ſuch a beam at an equal diſtance from the axis, the quieſcence of the rod would denote an equality between the weights acting upon it; but it is more convenient that ſome fixed poſition of the beam ſhould denote the equilibrium of the weights, and there is no poſition ſo eligible as that which is commonly uſed where the beam is horizontal, when the weights ſuſpended from the extremities of the arms are equal.

2. If the center of motion or fulcrum be a little above the center of gravity, the beam will not reſt in any poſition but the horizontal one; for when the beam is quieſcent, the center of gravity will be immediately under the center of motion; conſequently if it be removed from this ſituation, it will vibrate backwards and forwards, and at laſt reſt in an horizontal poſition.

The nearer the center of gravity of the beam is to the center of motion, the nicer will be the ballance, and the quicker it's vibrations; thus, if a c b c be the beam, and c the center of motion, the difference between the effect of having the center of gravity at K or c will be the ſame as if we compared the velocities of two pendulums of the lengths C K and C c, which I have ſhewn you to be in a ſubduplicate ratio of their lengths. The tendency to an horizontal poſition is however increaſed by lowering the center of gravity, in which caſe it will alſo require a greater additional weight to cauſe it to turn or incline to any given angle, and is therefore leſs ſenſible with a greater load.

3. When the fulcrum is below the center of gravity, if the center of gravity be moved out of the perpendicular line, the beam will be overſet, that is, turned out of it's horizontal poſition, and will not return thereto, ſo that equal weights may appear unequal.

The fixing the center of motion in a ballance is, you perceive, of the utmoſt importance, for upon this depends the caſe with which it will be affected by a ſmaller weight, and the readineſs with which it will return to it's horizontal poſition; and it is clear, from what I have already told you, that the beſt poſition is that in which the center of motion is a little above the center of gravity;

and even in this, it ſhould be proportioned to the diſtance of the weights from the fulcrum, and the quantity of matter to be weighed, which in different beams can only be attained by the practice and experience of the maker.

Hence great care is taken in all ballances, that the axis be placed a little higher than the center of gravity; to determine the beſt diſtance of theſe two points, an adjuſtment is added to ſome beams to raiſe or lower the center of gravity.

The ſcales ſhould be ſuſpended in ſuch manner, that in all poſitions the ſtrings of the ſcales may be parallel one to the other; for if this be not obſerved, the weights, although equal, will not be in equilibrio.

To impreſs more ſtrongly on your mind the alterations occaſioned by the different poſitions of the centers of motion and gravity, I have prepared a triangular piece of braſs, *fig.* 22, *pl.* 1, with three holes, one in the center of gravity, one above, and the other below that center.

Suſpend it on a pin paſſing through the center of gravity, and you ſee it will reſt in any ſituation; ſuſpend it on the hole above the center of gravity, and ſet the beam in motion by raiſing the center of motion, and you will obſerve it deſcend with an accelerated velocity, and it will continue oſcillating like a pendulum for a conſiderable time. When ſuſpended with the center of gravity above the center of motion, it will only be level; when the center of gravity is directly over the point of ſuſpenſion, if it preponderate ever ſo little, it will deſcend and not return.

When the arms of a ballance are unequal, the ballance is ſaid to be falſe, as not giving the true weight of the body weighed, whether it be ſuſpended from the ſhorter arm or from the longer one.

ıe. There are, however, ſeveral properties of the lſe ballance, which are extremely uſeful in the timation of weights, as well as in correcting errs which may have ariſen in the adjuſtment of ıe true ballance.*

A ballance with unequal arms will weigh as curately as another, provided the ſtandard weight ſelf be firſt counterpoiſed, then taken out of the ale, and the thing to be weighed be put into the ale and adjuſted againſt the counterpoiſe.

Or when proportional quantities only are condered, the bodies may be weighed againſt the eights, taking care always to put the weights in ıe ſame ſcale; for then, though the bodies may ot be really equal to the weights, yet their proortions amongſt each other will be the ſame as if ıey had been accurately ſo.

A weight which counterpoiſes an ounce when ıſpended from the longer arm of a falſe ballance, eing added to the weight which counterpoiſes an unce ſuſpended from the ſhorter arm, will always e greater than two ounces. The exceſs is that art of an ounce which is expreſſed by a fraction, f which the numerator is the ſquare of the differnce of the arms, and the denominator the product f the arms.

If any ſubſtance be ſucceſſively weighed from he longer and ſhorter arms of a falſe ballance, the rue weight will be a geometrical mean between he falſe weights.

Or

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* Nicholſon's Principles of Chemiſtry.
Atwood's Analyſis of a Courſe of Lectures.

OF THE STEEL-YARD.

On the *equilibrium* that ariſes from the ſuſpenſions of weights, when the diſtances are reciprocally proportioned thereto, is founded the *ſteel-yard*, which conſiſts of two arms of very unequal length, but equally poiſed by means of a weight annexed to the ſhorter, from which likewiſe a ſcale is ſuſpended to receive ſuch things as are to be weighed; the longer arm is divided into a number of equal weights, beginning from the axis, and ſuſtains a weight which ſlides from one end to the other, which weight being applied to the ſecond diviſion, will counterpoiſe double the weight in the ſcale of the ſhorter arm than what it will ballance when at the firſt diviſion, and triple when applied to the third diviſion, and ſo on, it being ſo graduated that the weight and diſtance are proportional.

HELSHAM'S PROPERTY OF THE BALLANCE.

If a man ſtanding in one ſcale, and counterpoiſed by a weight in the other, lays his hand to any part of the beam and preſſes it upwards, he will thereby deſtroy the ballance, and make the ſcale wherein he ſtands to preponderate.

To illuſtrate this property, fix the beam to the upper part of the pillar, *fig.* 4, *pl.* 4; A X is a perpendicular piece ſuſpended from the end A of the beam, and is prevented from being puſhed out of it's perpendicular poſition by the plate D G.

H I is a puſhing pipe, the lower point is put into a hole at X, the upper point is put into a ſmall hole on the under ſide of the beam; the point I, by means of a ſpiral ſpring, is preſſed up againſt the beam as a man might do with his arm.

The perpendicular piece A X, and the puſhing pipe being ſuſpended, the ſpring is prevented from acting; the whole is then counterpoiſed by weights on the oppoſite arm of the beam, the ſpring is then to be freed, and the beam immediately preponderates, and an additional weight muſt be hung to the oppoſite end to reſtore the equilibrium.

OF THE WHEEL AND AXIS.

The wheel and axis is a machine much uſed, and which is applied to a variety of purpoſes, and in a variety of forms. The *power* acts on the circumference of the wheel; the *weight* is faſtened to one end of a rope, whoſe other end winds round an axis that turns with the wheel.

This machine is generally uſed with a handle: thus, to wind up a jack I turn a handle, which motion coils a rope round the axis in the middle of the engine. By turning a handle we raiſe up a bucket from a well, &c. &c. but in all theſe caſes the greater the diſtance of the handle from the center of the wheel, the greater is the power we thereby obtain.

The axis A, and wheel C D, *fig.* 6, *pl.* 3,* are faſtened together, ſo that one cannot move without the other; when a *weight* is to be raiſed by this engine, it is fixed to the cord which goes round the *axis*, but the *power* is applied to ſome part of the *circumference* of the wheel.

To turn the wheel once round, pulling at the rope P, as much rope muſt be drawn off as winds once about the wheel, or through a ſpace equal to the circumference of the wheel; but whilſt the wheel is turning once round, the axis is alſo turned once round, and of courſe the rope by which the weight is ſuſpended will wind once round the axis, and the weight will be raiſed through a ſpace equal to as much rope as will go round the axis, i. e. equal to it's circumference.

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* At *fig.* 3, *pl.* 5, the apparatus A B C D E, is a compound engine, in which the wheel F may be detached to ſhew the nature of the wheel and axis.

Since therefore in the time the machine is turned once round, the ſpace which the *power* deſcribes, is equal to the circumference of the wheel; and the ſpace which the weight deſcribes is equal to the circumference of the axis, and as the velocities are as the ſpaces deſcribed in the ſame time; it follows, that *the velocity of the power is to the velocity of the weight, as the circumference of the wheel is to the circumference of the axis.*

Though this machine will preſent itſelf to you in a variety of forms, you will always find the above-mentioned proportion between the power and weight, when the power is applied to the circumference of the wheel, and the weight to the axis.

Hence on the *wheel and axis* the weight and power will be in equilibrio, when the power is to the weight as the circumference of the wheel is to the circumference of the axis; and the *momentum* of the power, or it's weight multiplied by it's velocity, *will be equal to the momentum* of the reſiſtance, or the weight multiplied by it's velocity.

Now geometricians prove that the circumferences of circles are as their diameters; conſequently, *if the power bears the ſame proportion to the weight, as the diameter of the axis bears to the diameter of the wheel,* the power and weight will ballance each other. Thus, ſuppoſe the diameter of the wheel to be eight inches, and the diameter of the axis to be one inch, then one ounce acting as a power P will ballance eight ounces as a weight W; and

W; and a ſmall additional weight will cauſe it to deſcend, and turn the wheel and it's axis, and ſo raiſe the weight W, and for every inch the weight riſes, the power will fall eight inches; ſo that

The *wheel and axis* may be conſidered as *a lever*, whoſe fulcrum is a line paſſing through the center of the wheel and the middle of the axis, and whoſe long and ſhort arms are thoſe radii of the wheel and axis that are parallel to the horizon, and from whoſe extremities the cords hang perpendicularly.

Suppoſe that the power does not act by a rope winding round a wheel, but that it is moved by a man's ſtrength applied immediately to the handles K, E, F, G, H, I; if the man firſt lays hold of the handle H, and puſhes it down to G, his hand paſſes through the ſpace H G, and the handle will be brought down to H; he then lays hold of I, and puſhes it to G, and ſo on, till he has turned the wheel once round; and his hand, which is now the power, will deſcribe the whole circumference of a circle, which is to be conſidered as the circumference of the wheel.

Hence a wheel and axis may be conſidered as a kind of *perpetual lever*, on whoſe arms the power and weight always act perpendicularly, though the lever turns round it's fulcrum; and in like manner when wheels and axes move each other by means of teeth on their circumference, ſuch a machine may be conſidered as a perpetual compound lever.

In uſing this machine the weight is not always ſuſpended to the axis by a rope, but is ſometimes fixed to the axis itſelf. This is the caſe of a bell that is moved in ringing by a wheel and an axis; here in once turning the wheel round, the velocity of the bell is as the circumference deſcribed by it's center of gravity.

On the other hand, in a crane wheel the power is not applied to the wheel by means of a rope, nor does it act upon any handle or ſpokes; but by a man walking within the wheel, as the man ſteps forwards, the part upon which he treads becomes the heavieſt part of the wheel, and deſcends till it be the loweſt; thus he keeps going on, and by treading upon every part of the wheel's circumference in it's turn, he walks over the whole thereof, and brings the wheel once round.

A capſtan is a cylindrical axis, that is turned by four (or more) bars that croſs it; theſe are the ſpokes of an imperfect wheel, and the velocity of the power applied to them is as the circumference which it deſcribes in one revolution of the capſtan.

When the parts of the axis differ in thickneſs, and weights be ſuſpended at the ſeveral parts, they may be ſuſtained by one and the ſame power applied to the circumference of the wheel, provided the product ariſing from the multiplication of the power into the diameter of the wheel, be equal to the ſum of the products ariſing from the multiplication of the ſeveral weights, into the diameters of thoſe parts of the axis from which they are ſuſpended.

Thus a weight of five ounces hung from a part of the axis whoſe diameter is one inch, and another of ten ounces from a part whoſe diameter is half an inch, will be both ballanced by a weight of two ounces hanging from the circumference of a wheel whoſe diameter is five inches; for five by one added to ten by one-half is equal to ten, which expreſſes the momentum of the weights; and two by five or ten is alſo the momentum of the power.

In reaſoning upon the wheel and axis, I have ſuppoſed the rope that ſuſtains the weight to be of no ſenſible thickneſs; but if it be a thick rope, or if there be ſeveral folds thereof round the axis, you muſt meaſure to the middle of the outſide rope to obtain the radius of the axis; for the diſtance of the weight is increaſed juſt ſo much by the coiling of the rope round the axis.

You have ſeen that the velocity of a weight, or any other force applied to the axis of a wheel, will increaſe as the circumference of the axis increaſes. Thus a weight, or any other force acting upon the axis B, will have a greater velocity than one which acts upon the axis A; if the force was applied to T, it's velocity would be ſtill further increaſed. Now the *fuſee* of a watch is an axis of the ſhape of a cone, and the ſpring by means of a chain acts upon the ſmalleſt part of this axis when the watch is wound up; as the watch goes down, the chain is applied to different parts of this cone, and to the thickeſt part of all when the watch is juſt down. Therefore as the elaſticity or abſolute force of the ſpring decreaſes, the velocity with which it acts to move the watch increaſes, by being applied to a larger part of the axis in proportion; and conſequently if the fuſee be properly regulated, the momentum produced in the wheels and the hands of the watch, will be always the ſame. In other words, *the motion of a watch is rendered uniform by the fuſee, though the force of the ſpring is not always the ſame, but is greateſt when the watch is wound up, and keeps decreaſing as the watch goes down.*

OF THE PULLEY.

The pulley is a ſmall wheel turning about it's axis, with a drawing rope paſſing over it; the ſmall wheel is commonly called a *ſheeve*, and is ſo fixed in a box or block, as to be moveable round a center pin paſſing through it.

Pullies are of two kinds: 1ſt, *Fixe* not move out of their place. 2d, *Move* riſe and fall with the weight.

A rope going round one or more raiſe a weight, is called the running *fixed pulley*; this kind only turns on it does not move out of it's place, ſee B, *f* or V, *fig.* 3, *pl.* 5. It changes the dire power, but gives it no mechanical ad that you can raiſe no greater weight b this pulley than you can raiſe without natural ſtrength.

Two equal weights ſuſpended to t ſtring that goes over a fixed pulley, wi each other, for they are equally ſtretc weights; and if either of them be p through any given ſpace, the other will r an equal ſpace in the ſame time; and c as the velocity and the weights are equal ballance.

Though this pulley gives no mec vantage, it is a ſource of great conveni takes off the neceſſity a man would ot under of aſcending along with the weig leſſens his labour; beſides having this f venience, that by means thereof the joi of ſeveral perſons may be made uſe of t and the ſame weight.

OF THE MOVEABLE PULLEY.

This kind C, *fig.* 4, *pl.* 3, or T, *fi* riſes or falls along with the weight, and momentum of the power.

Some writers have thought that the effects of the pulley might be beſt un conſidering a fixed pulley as a lever c kind, and a moveable pulley as one of

But this mode ſeems only calculated to introduce the parade of demonſtration, for the pulley cannot with propriety be called a lever; for when any power ſuſtains a weight by means of a ſyſtem of pullies, that power will ſuſtain the ſame weight *if the pullies be removed*, and the ropes be brought over the axis on which the pullies turned. Now in this caſe, no one I believe would ſay, that theſe axes ſhould be conſidered as levers; if it was required to raiſe a weight, there would be a very great reſiſtance ariſing from the friction of the ropes on the axes, and it is merely to avoid this reſiſtance that pullies are uſed, becauſe they turn upon their axis with very little friction.*

The beſt and moſt natural method of computing the proportion of any power, to the weight it ſuſtains by means of a ſyſtem of pullies, or of explaining their effects, is by conſidering, *that every moveable pulley hangs by two ropes equally ſtretched*, and which muſt conſequently bear *equal* parts of the weight; and therefore when one and the ſame rope goes round ſeveral fixed and moveable pullies, as all the parts on each ſide are equally ſtretched, the whole weight muſt be equally divided among all the ropes by which the moveable pullies are ſuſpended.

Hence if the power which acts on one rope be equal to the weight divided by the number of ropes, that power muſt ſuſtain the weight; in other words, the power and weight ballance each other, when the power is in proportion to the weight, as *one* is to the whole number of cords. Upon this principle the proportion of the power, to the weight it ſuſtains by means of a ſyſtem of pullies, may be computed in a manner ſo eaſy and

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* Hamilton's Four Introductory Lectures.

which a ſeparate ſtring goes round each pulley; one end thereof is fixed, while the other is joined to the moveable pulley next above it. There will be an equilibrium, *when the power is to the weight* as unity to that power of two, of which the index is the number of moveable pullies. See F, *fig.* 4. *pl.* 3.

The weight is faſtened to the lower pulley. The pullies do not here, as in the preceding ſyſtems, riſe together in one block with the weight, but act upon one another, ſo that each pulley doubles the power.

A power of one ounce will be in equilibrio with two ounces at A, with four at B, with eight at C, and with ſixteen at D; and the velocity of the power will be ſixteen times that of the weight. Though this ſyſtem be very powerful, yet as it raiſes weights very ſlowly, and takes up a conſiderable ſpace, it is very ſeldom uſed.

OF THE INCLINED PLANE.

The inclined plane is generally reckoned among the mechanic powers, being uſed with advantage in raiſing weights, by diminiſhing the weights laid thereon.

If hogſheads, or pipes of wine, &c. are to be let down into a cellar, or brought up out of it, a plank is laid along the ſtairs, which in that caſe is an inclined plane, the only mechanical power that can be readily applied. So alſo, in making reſervoirs for water, in gardening, in raiſing fortifications, &c. where carts cannot come, inclined planes made of wood ſerve for the wheelbarrows to run on, to remove the earth from a lower to an higher place.

I have already ſo far explained to you the properties of the inclined plane, that I need do little more, in this place, than ſhew you, that the leſs the plane is inclined to the horizon, the eaſier a body may be rolled or forced up it's ſurface.

If it were required to raiſe a heavy body to the height C B of the plane, *fig.* 6, *pl.* 4, and perpendicular to the horizon, it is evident you muſt employ a power equal to that of the weight, and it would even then be very inconvenient; but if an inclined plane, A B, be elevated to the height B, where the weight is to be raiſed, a leſs power than the weight will ſerve the purpoſe.

The weight is always moſt eaſily either drawn or puſhed in a line W w M, parallel to the plane, and paſſing through the center of the weight; for if one end of the line be fixed at W, and the other end inclined towards B, the body would be drawn againſt the plane, and the power muſt be increaſed in proportion to the greater difficulty of the traction: but if the line be carried above M, the power muſt be alſo increaſed; but here only in proportion as it endeavours to lift the body off the plane.

As the power acts to the greateſt advantage when the line of traction is parallel to the inclined plane, what I ſhall mention concerning this plane will principally apply to the line when in this ſituation. When ſo ſituated, there will be an equilibrium, *when the power is to the weight as the height of the plane is to it's baſe.* In other words, the mechanical advantage *is in proportion as the length of the plane exceeds it's height.*

Thus, if a weight of four ounces be laid on the plane R S, *fig.* 2, *pl.* 5, whoſe length is to it's perpendicular height as 2 to 1, it will be counterballanced by a weight of two ounces, drawing the other in a direction parallel to the plane, by means of a pulley properly fixed at the end thereof. If the length of the plane were to it's height as 4 to

1, it would be ſuſtained by one ounce, hanging freely, as in the former inſtance.

Hence, in drawing a cart or waggon up hill, if the power of the horſes be proportioned to the weight of the waggon, as the height of the hill is to it's ſide, the waggon will not run back, and a little additional power will draw it up hill.

OF THE WEDGE.

The wedge is the next mechanical power. Thoſe among you who have ſeen men cleave wood, cannot be at a loſs to know that the wedge is a piece of wood or iron, thin at one end, and thick at the back. The thin end is applied to the timber to be cleft, and the thick end ſtruck upon by an hammer.

Mathematicians have long debated concerning the true theory of the wedge. Hamilton, s'Graveſand, Deſaguliers, &c. aſſert that the power is to the reſiſtance, as half the back to the height. Keil, Whiſton, Nicholſon, &c. ſay, that it is as the whole of the back to the height.

There are many natural obſtructions to a complete theory of the wedge: among theſe are to be reckoned the friction, the elaſticity, and tenacity of the materials. Indeed the theory thereof will probably remain for a long time a matter of uſeleſs ſpeculation, ſince it is connected with a part of *phyſical* knowledge of which we are at preſent wholly ignorant; I mean the nature and force of adheſion in bodies, their tenacity, and the flexibility of the fibres. All theſe circumſtances, with many others, ſhew, that the experiments where preſſure is uſed as a power, cannot be adduced as illuſtrating the theory of this machine: for a wedge, when laden with a vaſt weight, will have ſcarce any effect in cleaving wood; whereas a blow upon the head of the wedge, will drive it eaſily into a hard body. *Percuſſion* puts all the parts of the wood into a tremulous motion; which, by diſuniting them, leſſens the ſtickage, and thereby facilitates the motion of the wedge. It has been alſo thought, that the motion communicated to the materials may, in ſome degree, contribute to the force of the wedge.

I ſhould therefore ſay no more on the ſubject of the wedge, if it were not neceſſary to explain to you that part of your mechanical apparatus which is conſtructed to prove the effects of the wedge. You muſt however perceive, from what I have juſt now mentioned, that this part of the apparatus cannot be adequate to the eſtabliſhing any theory. Experiments made therewith will ſhew the power of the wedge, according to the hypotheſis of the maker, but bear very little ſemblance to the natural action thereof.

The two pieces of braſs E H and G H, *fig.* 4, *pl.* 5, are joined at H, H by a hinge, and are drawn together by the threads h i, f g, going over the pullies i and g, having weights at the lower end of the cords. If a light wedge be drawn into this frame, by means of the weight I, hanging at the cord d e D, faſtened to the wedge, and going over the pulley e; if the weight L be in the ſame proportion to the weights R, I, as the half back of the wedge is to either of it's ſides, the weight which acts as a power for making the wedge go into the frame, will ballance the weight which pulls the ſide of the cleft, as a reſiſtance againſt the ſides of the wedge.

Thus ſixteen ounces on each ſide will ballance, or be equal to eight ounces of power at the back of the wedge, when the back is equal to the ſides.

But when the back is only half the length of one of the ſides, four ounces of power will be equal to ſixteen ounces of reſiſtance on each ſide.

Fig. 5, *pl.* 4, is another apparatus for illuſtrating the nature of the wedge. I K L M, and L M N O, are two flat pieces of braſs joined together by a hinge at L M; P is a graduated arch of braſs, on which the ſaid pieces of wood may be opened to any angle not exceeding ſixty degrees, and then fixed at the given angle by means of the two ſcrews a b; I K N O repreſents the back of the wedge, and I K L M, L M N O the two ſides of the wedge againſt which the wood acts in cleaving. By means of the arch P, the wedge may be ſo opened, as to adjuſt the thickneſs of the back in any proportion to the length of either of it's ſides, but not to exceed that length; and any weight, as *p*, may be hung to the wedge from the hook at the bottom thereof, which weight, together with that of the wedge, is the impelling power. A B, and C D, are two cylinders, to the edges whereof two flat plates are fitted, to prevent the wedge from ſlipping off edgeways from between them. A ſmall cord goes over the pivot at the end of eac cylinder; the cords S, T, belonging to the cylinde A B, go over the fixed pullies W and X, and ar faſtened at the other end to the bar *w x*, on whic any weight, z, may be hung. In like manner th cords R, Q, from the cylinder D C, go over th fixed pullies u v to the bar *vu*, from which a weig Y, equal to Z, may be hung. Theſe weights, drawing the cylinder towards one another, are be conſidered as the reſiſtance of the wood acti equally againſt the oppoſite ſides of the wedg The cylinders move on two bars, which are ſu ported by the pillars E, F, G, H, when the back the wedge is of the ſame length as either of the ſid The wedge with a weight p, ſufficient to make equal to forty ounces, will be in equilibrio agai

fo

forty ounces hanging at the lines belonging to each cylinder. If the back of the wedge be only half the length of the ſides, it will be in equilibrio with eighty ounces at each cylinder.

To the wedge are referred the axe or hatchet, the ſpade, chiſſels, needles, &c. in a word, all kinds of inſtruments which, beginning from edges or points, grow gradually thicker. A ſaw is a number of chiſſels fixed in a line; a knife may be conſidered as a chiſſel, when employed in ſplitting; but if attention be paid to the edge, it is found to be a fine ſaw, as is clear from it's producing a much greater effect by a drawing ſtroke, than would have followed from a direct action of the edge.

One conſiderable uſe of the wedge, is the raiſing up the beam of a houſe, to underprop it, when a floor begins to give way, by reaſon of too great a burden laid upon it; and ſo much force may be applied in this way, that ſome thouſand tons may be raiſed together with the floor, and all ſecured by means of this ſmall machine, which for this purpoſe is more convenient than either the ſcrew or the lever.

Of the Screw.

The mechanic power that next preſents itſelf for our conſideration, is the *ſcrew;* a machine of great efficacy in raiſing weights, or preſſing bodies cloſe together.

The ſcrew conſiſts of two parts; the firſt is called the male, or outſide ſcrew, being cut in ſuch manner as to have a prominent part going round the cylinder in a ſpiral manner, which prominent part is called the *thread* of the ſcrew; the other part, which is called the female, or inſide ſcrew, is a ſolid body, containing an hollow cylinder, whoſe concave ſurface is cut in the ſame manner as the convex ſurface of the male ſcrew, ſo that the prominent parts of the one may fit the concave parts of the other.

One part is commonly fixed, whilſt the other is turned round; and in each revolution the moveable part is carried, in the direction of the cylinder, through a ſpace equal in length to the interval between two contiguous threads; whereby the body to be moved is carried through a ſpace equal to that interval, which therefore expreſſes the velocity of the weight or reſiſtance, while the circumference, which is deſcribed by the power whereby the moveable part of the ſcrew is turned round, expreſſes the velocity of the power.

You may conceive how the ſcrew is made, by cutting a piece of paper into the form of an inclined plane, and then wrapping it round a cylinder. The inclined plane, riſing round the cylinder in a ſpiral manner, forms what is called the threads of the ſcrew. Now it is evident, that the ſcrew muſt be turned once round, before the reſiſtance can be moved from one ſpiral winding to another.

A ſcrew is ſeldom uſed without the application of a lever to aſſiſt in turning it; conſequently, as much as the circumference of a circle deſcribed by this handle or winch, is greater than the intervals or diſtance between the ſpirals, ſo much is the force of the ſcrew.

Thus, ſuppoſing the diſtance between the ſpirals to be half an inch, and the length of the winch to be twelve inches, the circle deſcribed by the handle of the winch, where the power acts, is nearly 76 inches, or 152 half inches, and conſequently 152 times as great as the diſtances between the ſpirals; and therefore a power at the handles, where the power acts, of no more than one pound, will ballance 152 pounds acting againſt the ſcrew; and as much additional power as is ſufficient to overcome the friction, will raiſe the 152 pounds.

There is therefore an equilibrium on the ſcrew, when the power is to the weight, as the diſtance between two contiguous threads is to the circumference deſcribed.

A very conſiderable degree of friction always acts againſt the force of the power in a ſcrew, but this is fully compenſated by other advantages; for on this account the ſcrew continues to ſuſtain a weight even after the power is removed, or ceaſes to act, and preſſes upon the body againſt which it is driven. Hence the ſcrew will ſuſtain very great weights; ſo that ſeveral ſcrews, properly applied, would ſupport a large building, while the foundation was mending, or renewed.

OF THE ENDLESS SCREW.

Sometimes a ſcrew is applied to a wheel, ſo as to ſerve as a pinion; it is then called *an endleſs ſcrew*, being one that turns on an axis, and may be turned perpetually. The teeth, or threads, of this ſcrew fit exactly into the teeth of a wheel, which are cut obliquely to anſwer thereto; ſo that, as the axis turns round, the threads of the ſcrew take hold of the teeth of the wheel, and, by turning it round, raiſe the weight.

The ſmall apparatus before you, ſee *fig*. 3, *pl*. 5, which is furniſhed with an endleſs ſcrew, will be ſufficient to illuſtrate the nature of it's force, or mechanical advantage.

The wheel C has a ſcrew on it's axis, working in the teeth of the wheel D, which ſuppoſe to be 48. It is plain, that for every time the wheel C, and ſcrew a b, are turned round, the wheel D will be moved one tooth by the ſcrew; and therefore, in 48 revolutions of the ſcrew, the wheel will have turned once round.

The diameter of the groove in the circle C, is equal to the diameter of the groove round the wheel D; but the velocity of the wheel C, is 48 times the velocity of the wheel D. Conſequently, if a line goes round the groove of the wheel D, and has a weight of 48 oz. ſuſpended from it's lower point, it will be ballanced by a weight of one ounce ſuſpended from a ſtring going round the groove of the wheel C.

If the line, inſtead of going round the groove of the wheel D, goes round it's axis, the power of the machine will be as much increaſed as the circumference of the groove exceeds the circumference of the axis; which, if it were ſix times, one ounce at H would ballance ſix times 48, or 288 ounces ſuſpended from the wheel C; ſo that the power or advantage gained is as 288 to 1. That is to ſay, a man, who by his natural ſtrength could lift an hundred weight, will be able to raiſe 288 hundred, or $14\frac{8}{20}$ ton weight by this engine.

The teeth of the wheel muſt be cut obliquely to anſwer the threads of the ſcrew, ſuppoſing it to lie in the plane of the wheel, and therefore the wheel will be acted on obliquely by the ſcrew. To remedy this, the ſcrew may be placed oblique to the wheel, in ſuch a poſition, that when the teeth are cut ſtrait or perpendicular to it's plane, the teeth of the ſcrew may coincide with and fit them, and the force be directed along the plane of the wheel.

At *fig*, 3, *pl*. 4, is repreſented another apparatus for ſhewing the power of the ſcrew. Here the tranſverſe arm is placed above the beam; as K L E is a ſcrew, M the female ſcrew; the upper part of the axis of the ſcrew paſſes through a hole, which prevents the ſcrew from any wabbling motion; G is a wheel attached to the ſcrew; a ſtring is wound round this wheel, and goes off on that ſide of the wheel which is next the tranſverſe arm, and ſo as to be a tangent to, and go over the pulley H, at the other end of the tranſverſe arm, and hanging down, any weight, as a power, to force down the ſcrew, may be ſuſpended. The point of the ſcrew preſſes upon one end of the beam, while the reſiſtance, or counterpoiſe, is placed at the other.

The ſcrew is of excellent uſe, not only in itſelf, for raiſing great weights, and other purpoſes, but in the conſtruction of ſeveral ſorts of compound engines.

The ſcrew, in moving a body, acts like an inclined plane. For it is juſt the ſame as if an inclined plane was forced under a body to raiſe it; the body being prevented from flying back, and the baſe of the plane being driven parallel to the horizon.

The uſe of this power is very great. It is of great ſervice for fixing ſeveral things together by the help of ſcrews; it is likewiſe very uſeful for ſqueezing or preſſing things cloſe together, or breaking them; alſo for raiſing or moving large bodies. The ſcrew is uſed in preſſes for wine, oil, or for ſqueezing the juice out of any fruit. The very friction of this machine has it's particular uſe; for when a weight is raiſed to any height, if the power be taken away, the ſcrew will retain it's poſition, and hinder the weight from deſcending again by it's friction, without any other power to ſuſtain it.

In the common ſcrew, ſuch as is here ſuppoſed, the threads are all one continued ſpiral, from one end to the other; but where there are two or more ſpirals, independent of one another, as in the worm of a jack, you muſt meaſure between

threads

thread and thread of the ſame ſpiral, in computing the power.

Of a micrometer ſcrew. The ſcrew is applied to, ſo many uſes, that it would be impoſſible to enumerate them all. Among other purpoſes, it is applied to great advantage for meaſuring or ſubdividing ſmall ſpaces: when uſed for this purpoſe, it is called a *micrometer.*

For this purpoſe, a ſcrew is ſo fitted to an inſtrument, that it may be turned round, or moved on it's axis, without moving backwards or forwards lengthways. A circular plate is fitted upon, and at right angles to the ſcrew. There is a female ſcrew fitting on the other, which carries a piece with a line to mark out the diviſions it paſſes over on the bar.

Suppoſe the ſcrew to have fifty turns, or threads, in an inch, the edge of the plate is divided into an hundred equal parts. Suppoſe the diviſion on the plate of the female ſcrew to be ſituated between two of the diviſions on the bar, by the micrometer it's diſtance from either is eaſily diſcovered.

To effect this, turn the ſcrew till the line on the female ſcrew exactly coincides with one of the diviſions, and the number of turns on the ſcrew, in producing the coincidence, will give the fiftieth part of an inch, and the odd diviſions on the plate will ſhew the number of hundredth parts of one turn; that is to ſay, the hundredth parts of one-fiftieth of an inch, or the five thouſandth part of an inch.

A GENERAL REMARK.

From what has been ſhewn, and proved to you, it follows, that the mechanic powers depend on one eaſy principle; a principle by which you may

ly compute the power not only of ſimple, but of
npound engines.

If we conſider bodies in motion, and compare
n together, we may do it either with reſpect to
uantities of matter they contain, or the velo-
ies with which they are moved. The heavier
body is, the greater is the power required,
her to move or ſtop it's motion. And again, the
ifter it moves, the greater is it's force. So that
e whole momentum, or quantity of force, in a
ving body, is the reſult of it's quantity of matter,
ltiplied by the velocity with which it is moved;
d when the products ariſing from the multi-
cation of the particular quantities of matter, in
y two bodies, by their reſpective velocities, are
ual, the moments, or entire forces, are ſo too.

Example. Suppoſe A to weigh forty pounds,
d to move at the rate of two miles in a minute;
d B to weigh only four pounds, and to move
enty miles in a minute; the entire forces with
ich theſe two bodies will ſtrike againſt any ob-
cle, will be equal to each other, and it would
refore require equal powers to ſtop them; for
multiplied by 2 gives 80, the ſame as is pro-
ced by multiplying 4 by 20.

This principle extends through the whole of
chanics. When two bodies are ſuſpended by
machine, ſo as to act contrary to each other,
the machine be put into motion, and the per-
dicular aſcent of one body, multiplied into it's
ght, be equal to the perpendicular deſcent of
other body, multiplied into it's weight, theſe
lies, however unequal in their weights, will bal-
ce one another in all ſituations; for as the
le aſcent of the one is performed in the ſame
e as the whole deſcent of the other, their re-
ctive velocities muſt be directly as the ſpaces
y move through; and the exceſs of weight in
body, is compenſated by the exceſs of velo-

city in the other: ſo that you may compute the power of any mechanical engine, by finding how much ſwifter the power moves than the weight; that is, how much further in the ſame time; and juſt ſo much is the power increaſed by the help of the engine.

THE PROPERTIES OF THE LEVER APPLIED TO INVESTIGATE THE STRENGTH OF BODIES.*

When the two arms of a lever are not in a right line, but contain an invariable angle, as at C, *fig.* 16, *pl.* 1, the law of equilibrium is the ſame as I have already explained; that is, if the power P be applied to the arm C B, and the weight W, by means of a pulley, in the perpendicular direction A M, on the arm C A, the power and weight will ſuſtain each other, if P be to W as C A to C B.

If ſeveral powers act upon the arm C A, find their center of gravity, A, on the arm C A, and ſuppoſe all the powers to be united there; and if the power P be to their ſum as C A to C B, it will ſuſtain them.

The ſum of the powers being given, it is manifeſt, that the farther their center of gravity is removed from their center of motion C, the greater the reſiſtance they will oppoſe againſt the power P, and it will require the greater force in the power to overcome them.

From this *Galileo* juſtly concludes, *that the bones of animals are ſtronger for being hollow.* Their weight being given, if C B F repreſent their length, the circle C H D a ſection perpendicular to that length, and P any power applied along their length, tending to break them; then the ſtrength or force of all their longitudinal fibres, by which the adheſion of the parts is preſerved, may be conceived to be united in A, the center of gravity of he circle C H D, which is the common center of ravity of thoſe forces, whether the ſection be a ircle or a ring. But it is plain, that the diſtance A of the center of gravity is greater when the ſection is a *ring*, than when it is a circle without ny cavity; conſequently the power with which the parts adhere, and which reſiſt againſt P, that endeavours to ſeparate them, is greater in the ſame proportion.

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* Maclaurin's Sir Iſaac Newton's Philoſophical Diſcoveries, p. 168.
Emerſon's Mechanics.

For the ſame reaſon, the ſtalks of corn, the feathers of fowls, and hollow ſpears, are leſs liable to accidents that tend to break them, than if they were of the ſame weight and length, but ſolid, without cavity.

In this inſtance we find, therefore, that *art nly imitates the wiſdom ſhewn in nature.*

In ſimilar bodies, engines, or animals, the greater are more liable to accidents than the leſſer, and have a leſs relative ſtrength; that is, the greater have not a ſtrength in proportion to their magnitude. A greater column, for example, is in much more danger of being broke by a fall than a ſimilar ſmall one. A man is in greater danger from accidents of this kind than a child; an inſect can bear a weight many times greater than itſelf; whereas a large animal, as a horſe, can hardly bear a burden equal to his weight.

To account for this, it is ſufficient to ſhew, that in ſimilar bodies of the ſame texture, the force which tends to break them, or to make them liable o hurtful accidents, increaſes in the greater bodies n a higher proportion than the force which tends o preſerve them entire, or ſecure, againſt ſuch ccidents.

Thus, let us ſuppoſe theſe cylindric beams BDE, FGHK, *fig.* 18, *pl.* 1, fixed in the nmoveable wall I L, and let us abſtract, in the ſize; and if there were any land animals mu larger than thoſe we know, they could hard move, and would be perpetually ſubjected to mo dangerous accidents. As to the animals of th *ſea*, the caſe is different, as the gravity of the wat in a great meaſure ſuſtains theſe animals. N does it avail to advance againſt this, that bon have been found which were ſuppoſed to have be longed to giants of an immenſe ſize, ſuch as th ſkeletons mentioned by *Strabo* and *Pliny*, of whic one was 60, the other 46 cubits high; for natura hiſtorians from juſt grounds have concluded, that in ſome caſes the bones were thoſe of elephant and in others thoſe of whales, brought to the places where they were found by ſome of thoſe revolutions that have happened in paſt ages.

From what has been ſaid it clearly follows that to make bodies, engines, or animals of equal relative ſtrength, the greater ones muſt have groſſer proportions. Thus, in order that the great cylinder A B D E, *fig.* 16, *pl.* 1, may be as firm and ſecure againſt accidents as the leſſer cylinder F G H K, the ſection A R E and it's diameter A E muſt be increaſed, till the effort ariſing from the adheſion of the parts bears as great proportion to the effort that tends to overcome this adheſion in the greater as in the leſſer cylinder: and this ſentiment being ſuggeſted to us by continual experience, we naturally join the idea of greater ſtrength and force with the groſſer proportions, and of agility with the more delicate ones.

In architecture, where the appearance of ſolidity is no leſs regarded than real firmneſs and ſtrength, this is particularly conſidered, in order to ſatisfy a judicious eye and taſte, the various orders of the columns ſerving to ſuggeſt different ideas of ſtrength. But by the ſame principle if we ſhould ſuppoſe animals vaſtly large, from the groſs proportions, a heavineſs and unwieldineſs would ariſe, which would make them uſeleſs to themſelves, and diſagreeable to the eye. In this as in all other caſes, whatever generally pleaſes taſte, not vitiated by education, or by fabulous and marvellous relations, may be traced till it appears to have a juſt foundation in nature; though the force of habits is ſo ſtrong, and their effects upon our ſentiments ſo quick and ſudden, that it is often no eaſy matter to trace by reflection the grounds of what we find pleaſing.

If ſeveral pieces of timber be applied to any mechanical uſe where ſtrength is required; not only the parts of the ſame piece, but the ſeveral pieces in regard to one another, ought to be ſo adjuſted for ſize, that the ſtrength may be always proportional to the ſtreſs they are to endure.

This propoſition is the foundation of all good mechaniſm, and ought to be regarded in all ſorts of tools and inſtruments we work with, as well as in the ſeveral parts of any engine. For who that is wiſe, will overload himſelf with his work tools, or make them bigger and heavier than the work requires? Neither ought they to be ſo ſlender as not to be able to perform their office. In all engines, it muſt be conſidered what weight every beam is to carry, and proportion the ſtrength accordingly. All levers muſt be made ſtrongeſt at the place where they are ſtrained the moſt; in levers of the firſt kind, they muſt be ſtrongeſt at the ſupport; in thoſe of the ſecond kind, at the weight; in thoſe of the third kind, at the power, and diminiſh proportionally from that point. The axles of wheels and pullies, the teeth of wheels, which bear greater weights, or act with greater force, muſt be made ſtronger; and thoſe lighter that have light work to do. Ropes muſt be ſo much ſtronger or weaker, as they have more or leſs tenſion;

ſion; and in general, all the parts of a machine muſt have ſuch a degree of ſtrength as to be able to perform their office, and no more. For an exceſs of ſtrength in any part does no good, but adds unneceſſary weight to the machine, which clogs and retards it's motion, and makes it languid and dead; and on the other hand, a defect of ſtrength where it is wanted, will be a means to make the engine fail in that part, and go to ruin. So neceſſary it is to adjuſt the ſtrength to the ſtreſs, that a good mechanic will never neglect it; but will contrive all the parts in due proportion, by which means they will laſt all alike, and the whole machine will be diſpoſed to fail all at once. And this will ever diſtinguiſh a good mechanic from a bad one, who either makes ſome parts ſo defective, imperfect, and feeble, as to fail very ſoon; or makes others ſo ſtrong or clumſey, as to outlaſt all the reſt.

From this general rule it follows, that *in ſeveral pieces of timber of the ſame ſort, or in different parts of the ſame piece, the breadth multiplied by the ſquare of the depth, muſt be as the length multiplied by the weight to be borne;* for then the ſtrength will be as the ſtreſs.

The breadth multiplied by the ſquare of the depth, and divided by the product of the length and weight, muſt be the ſame in all.

One obſervation more, before I quit the doctrine of equilibrium or ſcience of ſtatics, which is, to inform you that the writings of the *Platoniſts* and *Pythagoreans* cannot be properly underſtood without a knowledge thereof. Their alluſions to *arithmetic*, *geometry*, and *ſtatics*, are very numerous; *arithmetic* they conſidered as *the ſcience of mind; geometry* as the ſcience of *ethics* or moral virtue; and under *ſtatics* they couched *judiciary* and *political* knowledge.

They expreſſed their notions of the *principles* of all things in numbers; and *meaſure*, a geometrical term, was applied to moral action and virtue, as ſetting *due bounds* to the paſſions of the ſoul, marking out the lines of every duty, and aſcertaining the exact medium between the too little and the too much, in every affection, energy, and action. Mankind in general have agreed with theſe philoſophers, to uſe metaphors taken from ſtatics, to expreſs their opinions of the different degrees of *merit* and *demerit*, the ſubject of political juſtice. Thus the terms *heavy* and *light* are every where applied to *crimes* and *puniſhments*. Thus likewiſe an important ſervice to the ſtate is termed *weighty* and *momentous*, whilſt all little ones are termed *light* and of *ſmall moment*. Hence in all ages the *ballance* has been acknowledged as a fit emblem of *diſtributive* or *civil* juſtice; and the *rectangular rule* or *plumb-line* has been underſtood to be a ſymbol or mark aptly repreſentative of commutative juſtice. And the worth or *weight* of each part of the political ſyſtem is to be eſtimated by the greater or leſs importance or *moment* of it, to the preſervation of the ſyſtem; and by it's greater or leſs propenſity to adhere to the center of all civil union, the laws of the civil conſtitution.

OF COMPOUND ENGINES.

You have no doubt been often aſtoniſhed at the vaſt variety of compoſition, of which ſeven ſimple notes are ſuſceptible, and have contemplated with immenſe pleaſure the great quantity of words formed from the twenty-four letters of the alphabet, and the infinity of numbers produced from unity. In the ſame manner, from the ſimple machines I have deſcribed to you, compounded ones are formed by various combinations, ſo as to ſerve for different purpoſes, and yet the ſame general law takes place that I have already deſcribed to you, namely, that the power and weight ſuſtain each other when they are in the inverſe proportion of the velocities they would have in the direction wherein they act, if they were put in motion.

The mechanical powers, according to their different ſtructure, ſerve for different purpoſes; and it is the buſineſs of the ſkilful mechanic to chuſe or combine them in the manner that may be beſt adapted to produce the effect required. Beſides raiſing of weights and overcoming reſiſtances, one of the moſt uſeful problems in this ſcience, is that of making a regular movement that may ſerve to meaſure time with accuracy. It may, however, be proper to obſerve to you here, that machines ſeldom owe their origin or improvement to conſiderations deduced from the laws of motion; they are derived from other ſources. It is from long experience of repeated trials, errors, deliberations, corrections, &c. continued throughout the lives of individuals, and by ſucceſſive generations of them, that the practical ſciences derive their gradual advancement from aukward beginnings to their moſt perfect ſta e of excellence.

To be a good mechaniſt requires the labour of a whole life; it is an art rather perfected by practice than theory; the principles of mechaniſm may be learned in books, but the art muſt be acquired by experience.

The knowledge of machines, in a theoretical view, conſiſts in knowing how to employ a given power, ſo as to produce a required effect. To this end, it is neceſſary in the firſt inſtance to know accurately the nature and value of the power to be employed, and then to conſider of the means and manner of applying this power to the bodies to be put in motion, ſo as to obtain moſt advantageouſly the deſired effect.

If this effect can be obtained by ſimple machines, it is uſeleſs to employ thoſe that are compound; if a ſimple one is not ſufficient to anſwer the purpoſe, you muſt then have recourſe to thoſe that are compound.

TO COMPUTE THE POWERS OF COMPOUND ENGINES.

As notwithſtanding the combination of ſimple machines they ſtill preſerve their properties, the principles I have already laid down will be found ſufficient for computing the effects. 1. To diſcover the mechanical power of any engine, it will be ſufficient to meaſure the ſpace deſcribed in the ſame time by the power and the reſiſtance; for the power always ballances the weight, when it is in the ſame proportion as the velocity of the weight to the velocity of the power. Or, 2. By ſetting down the ratios of the power to the weight on each mechanical power, the ſum of theſe will be the ratio of the power to the weight; for when the ratio of the power to the weight is equal to the ſum of the ratios expreſſing the power and weight, there will be an equilibrium on each mechanic power.

Or,

1. Divide the machine into all the ſimple ones of which it is formed; then begin at the power and call it one, and by the properties of the mechanical powers, find the forces in numbers which the firſt ſimple machine exerciſes upon the ſecond. Call this force one, and find the force in numbers with which it acts upon the third; and putting this force as one, diſcover it's action on the fourth in numbers, and ſo on to the laſt. Then multiply all theſe numbers together, and the product will be the force of the machine, ſuppoſing the firſt power one.

2. *For wheel work*, take the product of the er of teeth in all the wheels that act upon or others for the power, and the product of the in all the wheels moved by them for the ignt: or inſtead of the teeth take the diameter.

Otherwiſe thus:

In wheel work, there are always two wheels ed upon one axis, or elſe one wheel and a pinion, rrel which ſupplies the place of a wheel. f theſe call that wheel the *leader* which is upon by the power, or ſome other wheel; all the other, which is upon the ſame axis, the *er*, driving another wheel forward. The receives the motion, the follower gives it.

Then having the number of teeth, or the diameter of each, *take the product of all the leaders for the weights, and the product of all the followers for the power.*

The product of all the leaders gives alſo the velocity of the power, the product of all the followers the velocity of the weight.

The principles being clear, it will be ſuperfluous to enter into the examination of a great number of machines; a few will be ſufficient to render you maſters of the ſubject.

OF SMEATON'S FULLIES.

I have already noticed to you ſome combinations of pullies. The conſtruction of this mechanical engine is ſo ſimple, that it is of little importance whether it be conſidered under the head of ſimple or compound engines. Some variations in the conſtructions thereof have been already noticed: I ſhall now lay before you the conſtruction of a tackle of pullies, contrived by that excellent mechanic *Mr. Smeaton*, and which is not ſo much known as it deſerves to be.

The pullies are in general arranged in their blocks, by being placed one by the ſide of the other on their pin, or one directly under the other upon ſeparate pins; but in either of theſe modes an inconvenience ariſes if more than three pullies are framed in one block.

If, according to the firſt method, three pullies are placed by the ſide of another, as the laſt line by which the draught is made, (or the fall of the tackle, as it is commonly called) muſt neceſſarily be upon the outſide pulley, the difference of their friction will give it ſo great a tendency to draw the block awry, that as much will be loſt by the rubbing of the pullies againſt the block on account of it's obliquity, as will be got by increaſing the number of lines.

The ſecond method is free from this objection; but as the length of the two blocks taken together muſt be equal to the ſum of the diameters of the ſix pullies, beſides the intervening ſpaces for the ropes, and the neceſſary appendages of the framing, they would run out into ſuch an inconvenient length, as to deduct very conſiderably from the height to which the weight might otherwiſe have been raiſed.

Hence it is evident that no very great purchaſe can be obtained by the common tackles of pullies alone; to increaſe it's power, a ſecond tackle is ſometimes fixed upon the fall of the firſt, but here the height to which the weight might have been raiſed by the firſt will be leſs in the ſame proportion as the purchaſe is increaſed by the ſecond.

Theſe impediments are obviated by Mr. Smeaton's contrivance; the pullies are here (*fig.* 6, *pl.* 5,) placed in each block in two tier, ſeveral being placed upon the ſame pin, as in the firſt method;

every one having another under it, as in the ſecond.

In this method all the lines are clear of one another, and the blocks are kept parallel. The model before you conſiſts of twenty pullies, five on each pin; with this model you may raiſe ſix hundred weight;* but with a tackle of this ſort properly executed in large, one man will eaſily raiſe a ton. Twenty is the largeſt number of pullies that anſwers well in practice.

The pullies are placed in two tier in each block, ſeveral being upon the ſame pin as in the firſt method, and every one having another under it as in the ſecond method; when the tackle is in uſe, the two tier that are the moſt remote from each other are ſo much larger in diameter than thoſe that are neareſt, as to allow the lines of the former to go over the lines of the latter without rubbing.

This conſtruction gives a new method of reeving the line upon the ſheeves; for here let the number of ſheeves be what they may, the fall of the tackle will always be upon the middle ſheeve, or that next the middle, according as the number of pullies on each pin is odd or even.

To reeve it, let the line be fixed to ſome convenient part of the upper block, and brought round the middle ſheeve of the large tier of the under block; from thence round one of the ſame ſort next to the middle one of the upper block; and ſo on, till the line comes to the outſide ſheeve, where the laſt line of the larger ſheeve falls upon the firſt ſheeve of the ſmaller, and being reeved round thoſe till it comes at the oppoſite ſide, the line from the laſt ſheeve of the ſmaller tier again riſes to the firſt of the larger, whence it is conducted round till it ends on the middle ſheeve of the upper block on the larger tier.

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* A large tackle was tried on board one of his Majeſty's ſhips, and though the rope was new, one man raiſed a ſhip gun and carriage of 2700 weight, there being a perſon to hold on to prevent the rope from ſlipping.

OF A COMPOUND ENGINE.

Fig. 1, *pl.* 5, repreſents a *compound engine*. The endleſs ſcrew is turned round by the wheel A B, the ſcrew takes into a wheel D C; on the axis of this wheel is a pinion E, that moves the wheel F G; to the axis H of this wheel the running rope of the pullies I K is fixed.

The diameter of the fly-wheel or lever is twice that of the wheel C D; the wheel C D has 64 teeth, the pinion E on the axis of this wheel has 10 teeth, the wheel F G has 80 teeth.

To calculate the force of this engine, multiply the diameter 2 of the fly by 64, the number of teeth in C D, which gives 128, and this product by 8, the number of times the pinion E moves round while the wheel F G moves once round, which gives 1024; multiply this by 3, becauſe the diameter of the wheel F G is three times that of it's arbor H, and you obtain 3072; which multiplied by 4, the advantage gained by the pullies, gives 12288 to 1 for the power of this engine, or 768 pounds to one ounce.

A B C D E F, *fig.* 2, *pl.* 6, is a ſmaller compound engine; the wheel or fly C has a ſcrew on it's axis, which works into the teeth of the wheel D which has 48 teeth, and the diameters of theſe two wheels are equal; but the wheel C moves 48 times round while the wheel D is moving once round; but the diameter of the wheel D is 6 times that of it's arbor, on which the cord is coiled that raiſes the weight; conſequently the power is as 6 times 48 or 288 to one, or one ounce will ſupport 288 ounces.

he upper part of *fig.* 2, *pl.* 5, and *fig.* 2, epreſented a compound engine, conſiſting evers acting one on the other; they are all ſt kind. In the firſt, R, the proportion is s 1 to 5; in the ſecond S, as 1 to 4; in the third , as 1 to 6; or as 1 to × 4 × 6, equal to 120; onſequently if the powe be to the weight as 1 to , they will counterp each other.

OF WHEEL WORK.

W eels with teeth are uſed in ſuch a variety s, that it will be neceſſary to explain in ſome e their nature and action. Although the computation of the numbers is not a part of mechanics, yet it is uſeful in the conſtruction of a variety of engines. From the nature of the wheel and axle it is clear, that the power or force on the pinion is to that on the circumference of the wheel on the ſame axis, as the diameter of the wheel is to that of the pinion.

Whether a wheel drives a pinion, or a pinion drives a wheel, the number of turns of the wheel multiplied by the number of it's teeth is equal to the number of turns that the pinion makes in the ſame time multiplied by it's teeth; ſo that the number of cotemporary turns of a wheel and pinion are reciprocally proportional to their number of teeth. Thus, if the number of teeth in a wheel be 80, and thoſe in the pinion 8, then the pinion will turn round 10 times to once of the wheel; therefore the *quotient of the wheel divided by the pinion it drives, is the ratio of turns to unity*; thus $\frac{80}{8}$ gives 10. Wheels and pinions are therefore generally expreſſed by fractions, the numerator bei the wheel, the denominator the pinion.

Hence if there be any number of wheels a upon ſo many contiguous pinions, and you di

: product of the teeth in the wheels by thoſe in : pinions, the quotient will be the number of ns of the laſt pinion, in one turn of the firſt ieel.

The number of turns may therefore be ex-eſſed by a fraction, whoſe numerator is the number teeth in the leading wheel, multiplied by it's imber of evolutions, and the denominator the imber of teeth in the wheel that is driven. Thus inion of 6 acting on a wheel of 52, will make it rn 3 times while it turns 26 times itſelf $\frac{6 \times 26}{52}$ ual 3.

If therefore you have a piece of wheel work, nſiſting of ſeveral wheels and pinions, *ex. gr.* if wheel of 48 acts on a pinion of 8, on whoſe axis ere is a wheel of 40 taking into a pinion of 6 rrying a wheel of 36, which moves a wheel of , on whoſe axis there is an index. The number turns made by the index while the firſt wheel es once round, will be expreſſed by this fraction, $\times \frac{40}{6} \times \frac{36}{6} = 240.$

Hence it is evident that any number of teeth the wheels and pinions, having the ſame ratio, ll give the ſame number of revolutions to an axis a given diſtance from the firſt, thus $\frac{64}{10} \times \frac{50}{8} \times \frac{36}{6}$ ve 240 like the preceding combination; it is erefore left to the ſkill of the artiſt to determine at numbers will beſt ſuit the general deſign and cumſtances of his machine.

Thus the ſame motion may be performed ei-r by one wheel and pinion, or many wheels and ions, provided the number of turns of all the eels bear the ſame proportion to all the pinions ich that one wheel bears to it's pinion.

Theſe principles conduct us to a rule, whereby

OF THE ADVANTAGES GAINED BY MACHINES.

I have ſhewn you in treating of ſimple machines, that as much as was gained in force ſo much was loſt in time, ſo that the effect produced by a given power in a given time is always [illegible] ſame, whatſoever machine is uſed; you have alſo ſeen that this propoſition holds good in all compound engines, that is, in whatever proportion the power is leſs than the weight, in the ſame proportion will the weight be ſlower than the power.

In order therefore to obtain a juſt idea of the advantages gained by machines, ſuppoſe a man by a fixed pulley raiſes a beam to the top of a houſe in two minutes, it is clear that he will be able to raiſe ſix beams in twelve minutes; but by means of a tackle with three lower pullies, he will raiſe the ſix beams at once with the ſame eaſe as he before raiſed one, but then he will be 6 times as long about it, that is 12 minutes; thus the work was performed in the ſame time, whether the mechanical power was uſed or not. But the convenience gained by the power is very great, for if the ſix beams be joined in one, they may be raiſed by the tackle, though it would be impoſſible to move them by the unaſſiſted ſtrength of one man.

Conſequently, if by any power you are able to raiſe a pound with a given velocity, it will be impoſſible by the help of any machine whatever, with the *ſame power*, to raiſe two pounds with the ſame velocity; yet by the aſſiſtance of a machine you may raiſe two pounds with half that velocity, or even one thouſand with the thouſandth part of that velocity; but ſtill there is no greater quantity of motion produced when a thouſand pound is moved than when one pound, the one thouſand

pounds

ounds moving proportionably ſlower. The power f machines conſiſts only in this, that by their means the velocity of the weight may be diminiſhed at pleaſure, ſo that with a given force any given reſiſtance may be overcome.

The motion of the weight is not at all increaſed by any engine, it's velocity only is thereby ſo much diminiſhed, that the *quantity of motion* of the weight may not exceed the quantity of motion in the power.

By machines, a power otherwiſe incapable of communicating motion to, or ſupporting the preſſure of a body, may effect it's purpoſe by transferring a part of the weight upon a fulcrum, diſtributing it amongſt a number of pullies, or placing it upon an inclined plane or ſcrew; and by this artifice a power may keep a weight ſuſpended which exceeds it in any aſſigned proportion, though without any acquiſition of moment in a given direction: for motion is only communicable according to the eſtabliſhed natural relations ſubſiſting between matter and motion, and the magnitudes of two powers in equilibrio are always inverſely as their velocities.

It is therefore in vain to think of moving a greater weight by a ſmall power, and with the ſame velocity as with a greater power. No real gain of force is acquired by mechanical contrivance; on the contrary, force from friction, &c. is always loſt, the advantages obtained are confined to convenience; for inſtance, by machines we are enabled to give a convenient direction to the moving power, and to apply it's action at ſome diſtance from the body to be moved, which is a circumſtance of almoſt infinite importance. By machines we can alſo ſo modify the energy of the moving power, as to obtain effects which it would not produce without modification.

Mechanics does not teach us to make but to apply powers, ſuch as we find them in nature; for we deceive ourſelves if we think that by the means of any engine one man ſhall do the work of two in the ſame time, ſuppoſing him to employ the ſame ſtrength.

In the performance of ſeveral works, where we have ſufficient ſtrength, we often want time; and where we have time to ſpare we want ſtrength. In theſe caſes the mechanic has an opportunity of directing the application of the powers according to time.

Thus in making harbours, carrying on dykes, moles, or banks, where at every tide the ſea may damage the work, and a ſpring tide over ſet it, the *greateſt number of hands* muſt be employed that can work one by another. In ſome caſes, as raiſing great blocks of marble or other heavy goods out of a ſhip to lay them on a wharf, *many hands* cannot be employed; here then an engine may be uſed, where one man may do the work of ten or twenty men, but he ſhall be ten or twenty times longer in performing it. And the engine is abſolutely neceſſary, becauſe without it the work could not be performed; a ſufficient time muſt therefore be employed, without which a great ſtrength would be of no uſe. In draining mines you are generally confined to time, becauſe the ſubterraneous ſprings ſupply the water while a force is employed to draw it out; here then the intenſity of the power muſt be ſuperior to the quantity to be raiſed in a certain time.

When great manufactures are carried on, mechaniſm may often be employed to great uſe; thus, ſuppoſe that in winding of ſilk fifty men being employed, ſhould only move a weight equal to half a pound, while they carry their hand round; whereas one man can eaſily raiſe twenty-five pounds with the ſame velocity as his hand moves round in his inſtance, and that for ten hours in a day: here a machine may be applied, whereby one man employing his whole ſtrength ſhall do the work of fifty men in the ſame time. In other caſes machines may afford great profit by rendering effectual the force or intenſity of the power or powers employed as in the fire-engine, water-wheel, &c.

OF THE REGULATION OF MOTION BY FLY-WHEELS.

A uniform motion is continued by applying the heavy wheel, (or a croſs bar loaded with equal weights called a fly) to the machine; this being made to revolve about it's axis, keeps up the force of the power, and diſtributes it equally in all parts of it's revolution, by going on at the ſame rate it makes the motion uniform, for on account of it's weight a ſmall variation in force does not ſenſibly alter it's motion, while it's friction and the reſiſtance of the machine prevents it from accelerating. If the motion of the machine ſlackens, it helps it forward; if it tends to move too faſt; it will keep it back.

Every regulating wheel ſhould be fixed upon that axis where the motion is ſwifteſt, and ſhould be heavy when the motion is deſigned to be ſlow, and light where it is to be ſwift. In all caſes, the center of motion ſhould coincide with the center of gravity of the wheel. The axis may be either perpendicular or parallel to the horizon

Moſt mechanical operations conſiſt either in communicating motion to quieſcent bodies, or in overcoming reſiſtance; in which operations the actions of the moving force, and it's effects, are not always cotemporary; but motion is frequently firſt generated, and at ſubſequent times, employed in producing the reſult. Thus great mechanical effects may be produced by means of ſmall velociti generated in ponderous bodies by inconſiderabl moving forces. Suppoſe an heavy cylinder, of iro or lead, moveable about it's axis, and in a vertic plane; a ſmall force being applied to turn the cylinder, will, if long continued, generate ſuch a forc as will produce effects in raiſing weights by a means obtainable by the moving force immediatel applied.

Mr. Atwood has ſhewn, that a force of twenty pounds, applied for thirty-ſeven ſeconds to the circumference of a cylinder of ten feet radius, and weighing 4713 pounds, would, at the diſtance of one foot from the center, give an impulſe to a muſquet-ball equivalent to what it receives from a full charge of gunpowder.

The ſame effect would be produced in fix minutes ten ſeconds, by a man turning the cylinder with a winch one foot long, on which he conſtantly exerted a force of twenty pounds.

This accumulation of mechanic force appears extraordinary at firſt ſight, and may ſuggeſt wrong notions concerning the ſubject, unleſs fully conſidered; when it will appear, that the cylinder has no principle of motion in itſelf, and cannot have any more than it receives.

An accumulation of motion in ponderous wheels, is, as I have juſt obſerved, of great ſervice when applied to practical purpoſes. Thus machines to lift weights, to grind corn, &c. as well as many others, having a large ponderous wheel (termed a *fly*) fixed to ſome part of their machinery, ſo that it ſhall revolve round it's axis, have been found to produce much greater mechanical effects than could have been produced without ſuch an additional maſs of matter.

Here, however, I muſt beg you to obſerve, that there is no *increaſe* of power communicated to any engine by *flies*, *ballaſt-wheels*, &c. they act upon quite another principle.

In all machines in which flies are uſed, either a conſiderably greater force muſt be applied than what is neceſſary to move the machine without it, or the fly muſt have been ſet in motion ſome time before it is applied to the machine.. It is this ſuperfluous power which is, as it were, collected by the fly; and ſerves as a reſervoir, by which the machine may be ſupplied when the effort of the power is leſſened.

Suppoſe a wheel and axle (with a ponderous wheel affixed to it), moveable round an axis by means of an handle, which is impelled by muſcular force. Now here the uſe of a ponderous wheel is evident; for ſuppoſe a certain uniform motion generated therein, this will continue for ſome time to raiſe the weight, although the moving force of the arm be diſcontinued, which muſt in ſome degree happen when the arm is aſcending. Now if there were no motion in the ponderous wheel, to continue the aſcent of the power, the reſiſtance would begin to preponderate as ſoon as the moving power was at all diminiſhed; from which it is manifeſt how much motion would be loſt without the fly.

It is a reſervoir to ſupply the machine when the animal ſlackens his efforts; and this is always the caſe with animals, for none are able to exert a great power with abſolute conſtancy. When he begins to move the machine, he is vigorous, and exerts a great power; which not only overcomes the reſiſtance of the machine, but communicates a conſiderable degree of power to the fly. Hence the machine, when moving, yields for a time to a ſmall impulſe; during which time the fly acts as a moving power, and the animal recovers his ſtrength.

By degrees, however, the motion of the machine decreaſes, and the animal is then obliged to renew his efforts. In this caſe, if it were not for the fly, the velocity of the machine would be conſiderably increaſed; but it now acts as a reſiſting power, and the greater part of the ſuperfluous motion is lodged therein, ſo that the increaſe of velocity in the machine is ſcarcely perceptible; and the animal again acquires time to reſt himſelf, till the machine requires an increaſe of impulſe; and ſo on alternately.

It is the ſame with a machine moved with water, or by a weight; for though the ſtrength of theſe does not exhauſt itſelf like muſcular force, yet the yielding of the parts of the machine renders the impulſe much leſs after it begins to move: hence it's velocity is accelerated for ſome time, till the impulſe becomes ſo ſmall, as to require an increaſe of power to keep up the neceſſary motion; but when the impuſe ſlackens, the fly communicates part of it's motion, ſo as to render the motion equable. The truth of what has been advanced, will be rendered ſenſible by conſidering the inequality of motion in a clock, when the pendulum is off; and how very regularly it goes when regulated by the pendulum, which acts as a fly.

Flies are particularly uſeful in any kind of work which is done by alternate ſtrokes; as the lifting of large peſtles, pumping of water, &c. In this caſe the weight of the wheel employed is a principal object; and it is calculated by a compariſon with the weight to be raiſed.

Thus, ſuppoſe it to be required to raiſe a peſtle thirty pounds weight to the height of one foot ſixty times in a minute. Let the diameter of the fly be ſeven feet, and ſuppoſe the peſtle to be raiſed once at every revolution of the fly, we muſt then conſider what weight, paſſing through 22 feet in a ſecond, will be equivalent to 30 pounds, moving through one foot in a ſecond. This will be [illegible] by [illegible], or [illegible] pounds. When a fly of this kind is to be [illegible] [illegible], and the machine ſet a going, the fly would be able to lift the peſtle once after the moving power was withdrawn; but by increaſing the weight of the fly to ten, twelve, or twenty pounds, the machine, when left to itſelf, would make a conſiderable number of ſtrokes, and be worked with much leſs power than if no fly had been uſed. It is certain, however, that the fly does not communicate any abſolute increaſe of motion to the machine; for if a man, or any animal, is not able to ſet any mechanical engine in motion without a fly, he will not be able to do it though a fly be applied; nor will he be able to keep it in motion, though ſet a going with a fly, by means of a greater power.*

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* Encyclopædia Britannica, vol. [illegible] page [illegible]

LECTURE XXXII.

OF THE DIFFERENCE BETWEEN PRACTICE AND THEORY IN MECHANICS.

I HAVE, in what I have already ſaid on theſe ſubjects, paid very little attention to the phyſical properties of the materials of which machines are compoſed, or of the alterations theſe properties occaſion in their effects. The propoſitions that are demonſtrated with the utmoſt mathematical rigour, are not found to anſwer in practice, and the difference can only be allowed for and eſtimated by experimental inveſtigation.

In eſtabliſhing the theory, I have ſuppoſed that machines did not rub againſt each other, and ſo interrupt their uſual workings; I ſuppoſed that all the planes on which they moved were even, all the levers inflexible, and that the air gave no reſiſtance: but this is not the caſe in practice; all theſe are impediments.

Whenever motion is communicated to a body, a certain reſiſtance muſt have been overcome by the moving force. This reſiſtance is of various kinds: 1. The inertia of the maſs moved. 2. That of it's weight, or other abſolute force, oppoſed to the action of the moving power. 3. Obſtacles by which the moving body is retarded in it's progreſs. Many circumſtances relative to the moving forces which are exerted on bodies, in order to produce motion, muſt be attended to in order to proportion the means to the end, and to produce the deſired

ted effect, with [illegible]
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ments, parti[illegible]
e in the[illegible]
it will [illegible]
g theory [illegible]
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n, a[illegible]
[illegible]
to [illegible]

A great number of experiments were made with hard bodies, or thoſe whoſe parts ſo firmly cohered, as not to be moved *inter ſe* by the friction, and in each experiment bodies of very different degrees of friction were choſen, but the reſults all agreed; we may therefore conclude, that *the friction of hard bodies in motion is a uniformly retarding force.*

Experiments were made to determine whether the ſame law obtained for bodies when covered with cloth, woollen, &c. and it was found, in all caſes, that *the retarding force increaſed with the velocity;* but upon covering bodies with paper, the conſequences agreed with thoſe already related.

The next queſtion is to determine *whether friction,* cæteris paribus, *varies in proportion to the weight or preſſure.* Now if the whole quantity of the friction of a body, meaſured by a weight without inertia equivalent to the friction, increaſes in proportion to the weight, it is manifeſt that the retardation of the body, ariſing from friction, will not be altered; for the retardation varies as $\frac{\text{quantity of friction}}{\text{quantity of matter}}$: hence, if a body be put in motion upon the horizontal plane by any moving force, if both the weight of the body and the moving force be increaſed in the ſame ratio, the acceleration ariſing from that moving force will remain the ſame, becauſe the accelerative force varies as the moving force, divided by the whole quantity of matter, and both are increaſed in the ſame ratio; and if the quantity of friction increaſes alſo as the weight, then the retardation from the friction will, from what has been ſaid, remain the ſame, and therefore the whole acceleration of the body will not be altered; conſequently the body ought, upon this ſuppoſition, ſtill to deſcribe the ſame ſpace in the ſame time.

Hence

e ſame time, when both the body and moving rce are increaſed in the ſame ratio, you may de- :mine whether the friction increaſes in propor- on to the weight.

A body weighing 10 oz. by a moving force of oz. deſcribed in 2″ a ſpace of 51 inches; by load- g the body with 10 oz. and the moving force th 4 oz. it deſcribed 56 inches in 2″; and by ading the body again with 10 oz. and the moving rce with 4 oz. it deſcribed 63 inches in 2″.

A body whoſe weight was 16 oz, by a moving rce of 5 oz. deſcribed a ſpace of 49 inches in 3″; ading it with 64 oz. and the moving force of oz. the ſpace deſcribed was 64 inches.

From theſe experiments, and many others of e ſame kind, it appears, that the ſpace deſcribed always increaſed by increaſing the weight of the dy and the accelerative force in the ſame ratio; d as the acceleration ariſing from the moving ce continued the ſame, it is manifeſt that the ardation ariſing from friction muſt have been niniſhed, for the whole accelerative force muſt ve been increaſed, on account of the increaſe of : ſpace deſcribed in the ſame time; and hence, the retardation from friction varies as the $\frac{\text{ntity of friction}}{\text{antity of matter}}$, *the quantity of friction increaſes ı leſs ratio than the quantity of matter, or weight he body.*

The third queſtion Mr. Vince propoſed to de- nine was, *Whether the friction varies by varying ſurface on which the body moves?*

Let us call the greater ſurface of the body A; leſſer ſurface *a*. Now the weight on every en part of *a*, is as much greater than the weight an equal part of A, as A is greater than *a*. If, efore, the friction was in proportion to it's ght, it is manifeſt, that the friction on *a* would be equal to the friction on A; the whole friction on A being, on ſuch a ſuppoſition, as the weight on any given part of each ſurface multiplied into the number of ſuch parts, or the whole area, which products, from the above proportion, are equal.

But, from the laſt experiments, it has been proved, that the friction on a given ſurface increaſes in a leſs proportion than the weight; conſequently the friction on any given part of *a*, has a leſs ratio to the friction on any equal part of A, than A has to *a*; and hence the friction on *a* is leſs than that on A; *that is, the ſmalleſt ſurface has always the leaſt friction*, contrary to what has been generally concluded.

In trying the experiments on this head, care muſt be taken to chooſe ſuch bodies as have exactly the ſame roughneſs, with a regular grain, without knots; or an equal degree of roughneſs may be obtained by paſting ſome fine rough paper on each ſurface.

A body was taken, whoſe ſurface was to it's edge as 22 to 9; with the ſame moving force it deſcribed on it's flat ſurface 33½ inches in 2″, on it's edge 47 inches in the ſame time.

One whoſe ſurfaces were as 32 to 3, and with the ſame moving force, deſcribed on it's flat ſide 32 inches in 2″, on it's edge 37 inches in the ſame time.

From theſe and many more experiments of the ſame kind, it appears, that the ſmalleſt ſurface had always the leaſt friction; we may therefore conclude, that the friction of a body does not continue the ſame when it has different ſurfaces applied to the plane on which it moves, but that the ſmalleſt ſurface will have the leaſt friction.

The experiments which have been heretofore made on this ſubject, have been inſtituted to find what moving force would *juſt* put a body at reſt in

otion; and they concluded from thence, that the
celerated force was then equal to the friction:
it it is manifeſt, that any force which will put a
dy in motion, muſt be greater than that which
ppoſes it's motion, otherwiſe it would overcome
; and, conſequently, if there were no other ob-
ction, the friction could not be accurately aſcer-
ined: but there is another objection, which to-
lly deſtroys the experiment, ſo far as it tends to
ew the quantity of friction which is the adheſion
f the body to the plane while it lies at reſt, which
i confirmed by experiments.

Thus a body of 12¼ oz. was laid upon an ho-
izontal plane, and then loaded with a weight of
lb; and ſuch a moving force was applied, as
'ould, *when* the body was juſt *put* in motion, con-
nue that motion without any acceleration, in
hich caſe the friction muſt be juſt equal to the
ccelerative force. The body was then ſtopped;
hen it appeared that the ſame moving force
hich had *kept* the body in motion before, would
ot put it in motion: it appears, therefore, that
iis body, when laid upon the plain at reſt, ac-
iired a very ſtrong coheſion to it.

A body whoſe weight was 16 oz. was laid at
ſt upon the horizontal plane, and it was found
at a moving force of 6 oz. would juſt *put* it in
otion; but that a moving force of 4 oz. *would*,
hen it was juſt put in motion, *continue* that mo-
on; and therefore the accelerative force muſt *then*
ve been equal to the friction, and not when the
oving force of 6 oz. was applied.

Theſe experiments ſhew how very conſiderable
e *coheſion* was, in proportion to the friction,
en the body was in motion; it being in the lat-
r caſe almoſt one-third, and in the former very
ar the whole friction. All the concluſions,
erefore, deduced from experiments inſtituted to

determine the friction from the force neceſſary to *put* a body in motion, have been *manifeſtly falſe*, as ſuch experiments only ſhew the reſiſtance which ariſes from coheſion.

I ſhall conclude this article with a few general obſervations on friction; and adviſing you, in all caſes, to have recourſe to experiments and on the engines themſelves, to know the reſiſtance occaſioned by friction.

To leſſen the quantity of friction, the parts are often made of different materials; as iron axes are made to work in braſs or bell-metal collars, as, from the diverſity in the pores of the different ſubſtances, they are leſs apt to adhere or ſtick together. Care is alſo taken to poliſh the parts, and make them as ſmooth as poſſible.

Wood, and all metals, when greaſed and oiled, have nearly the ſame friction. Where wood acts againſt wood, greaſe makes the motion twice as eaſy. Wheels greaſed or tarred go four times eaſier than when wet.

The friction increaſes with the weight, though not in the ſame proportion: it is alſo augmented, except in a very few caſes, by an increaſe of velocity. A great ſurface alſo occaſions ſomewhat more friction with the ſame weight and velocity: yet friction may be increaſed by too little ſurface to move on; as upon clay, &c. where the body ſinks in.

The friction of a ſingle lever is very ſmall. Pullies are ſubject to great friction, becauſe their diameters, in general, are very ſmall in proportion to their axes, becauſe they very often bear againſt the blocks, and from the wear of the holes and axles.

The friction of the wheel and axle is as the weight upon it, and the diameter of the axis, the ſtiffneſs of cords, &c.

In a ſcrew there is a great deal of friction.
oſe with ſharp threads have more friction than
ſe with ſquare threads, and endleſs ſcrews have
re than either.

Some writers have conſidered bodies moving
over the other in two different manners.
us we may, 1. apply the ſame parts of one to dif-
ent parts of the other; as when you make a book
le on a table, or as in the experiments of Mr.
nce. Or, 2. you may make different parts of
e ſurface ſucceſſively touch the different parts of
e other; as when you make a ball roll upon a
lliard table.

This latter ſpecies of friction is never ſo
werful in retarding motion as the former kind;
which you have an evident and familiar proof,
the cuſtom of dragging the wheels of carriages
hen the deſcent is too deep; for when they are
raid that a coach or waggon ſhould go too faſt
wn a hill, they hinder the wheels from going
und their axis: conſequently, the ſame point of
e circumference drags ſucceſſively upon a num-
r of points on the ground, which conſiderably
tards the motion of the carriage. It is not ſo
en every wheel turns in the uſual way about it's
is.

This may be further illuſtrated by the appa-
us with friction wheels, which I uſed in a former
ture, in illuſtrating the theory of accelerated
tion. To this end I place the axis of the pen-
um in theſe two pivots, and then put it in mo-
n. It is now a friction of the firſt kind, as the
indrical axis paſſes ſucceſſively over the lower
t of each of the holes.

Let us now place the axis of the pendulum upon
interſection of the two pair of rollers, and put
pendulum in motion, which motion will cauſe
rollers to turn, and thus be only a friction of

the ſecond kind, the circumference of one rolling on the circumference of the other, the part which touched before now touching no longer, the parts being alſo in a favourable direction for diſengaging themſelves from each other, and you will find that it will now go a much longer time than before.

Mr. Garnet, has obtained a patent for a new and ingenious application of this principle. Between the axle and nave of any wheel-work, a ſpace is left to be filled up by ſolid equal rollers, nearly touching each other; theſe have axes, which are inſerted into a circular ring at either end, whereby their relative diſtances to each other are preſerved, and they are kept parallel to each other, becauſe the circular rings are faſtened together by ſmall ſupports which paſs between the rollers.

OF MAN CONSIDERED AS AN ARTIFICIAL MACHINE.*

Man has been conſidered by anatomiſts, as a ſyſtem of all the artificial machines united in the human fabric; they have found the lever, the pulley, the axle in the wheel, the wedge, and even the ſcrew, or at leaſt ſomething reſembling each of them, in his perſon: thus his arms have been likened to levers; his head turning upon it's axle; the digaſtric muſcle, that aſſiſts his ſwallowing, to a rope running over it's pulley; the glands as lifting up their fluids in the manner of an artificial water-ſcrew; and his teeth have been compared to wedges. But ſome have not ſtopped here; they have gone on not only to pleaſe themſelves with the reſemblance, but to eſtimate the force of man through all his vital and involuntary motions; ſuch as the running of the blood through his veins, the drawing his breath, and ſuch like, by the inflexible laws of mechaniſm. They have even applied geometrical rules to meaſure objects conſtantly in change, and built theories upon proportions they were unable to diſcover. Thus, when *Borelli* once got the hint of comparing the muſcles, or fleſhy parts, to cords, he then readily built his theory, and calculated the human force by conſidering the thickneſs of the cords, and the length of the lever. Thus, when another found the ſimilitude between the blood running through it's channels, and water ſpouting through pipes, he purſued the ſpeculation, till he at laſt was taught to believe, that vomits would cure a ſpitting of blood, and bathing in warm water would be a remedy for the dropſy: happy, however, had his theory never been put into practice.

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* Goldſmith, Survey of Experimental Philoſophy, vol. i. p. 245 to 369.

It is as impoſſible to determine the muſcular force of any man by the bare inſpection or admeaſurement of his muſcles, as it is to meaſure the ſwiftneſs of the circulation of his fluids by the ſpouting of his blood from a vein. Neither can be done, though *Cheyne* has pretended to demonſtrate, that if we compare the muſcular ſtrength of two animals, that animal whoſe fluids circulate twice as ſwift, will be ſix times as ſtrong. *Friend* and *Wainwright* adopted his demonſtration, for he called it a demonſtration; and indeed it was drawn up with a ſufficient degree of mathematical parade. *Martine*, however, in a treatiſe entitled "*De Similibus Animalibus*," has demonſtrated that *Cheyne*'s demonſtration was falſe; but it was in order to eſtabliſh another demonſtration of his own. He aſſerted that the force in ſimilar animals was as the cube roots of the fourth powers of the limb put into motion. You do not, perhaps, underſtand the preciſe [illegible] words. But it is no mat-ter, [illegible] is such as the former.

[illegible] of the mufcles in [illegible] impoffible to determine [illegible]. The ftrength of the mufcle is gene-rally [illegible] the exercife it has been [illegible] the legs of a chair-man are ftronger [illegible] it is the fame with the arms of a [illegible], to ufe the words of a [illegible], who miftook his man and [illegible], we can never know the ftrength of the [illegible] we experience their effects.

But though we cannot determine, with any precifion, of two men which are ftrongeft, yet in the fame man we can compare the force of his mufcles with rather more precifion. This, at leaft, can be faid with great certainty, that thofe mufcles which are inferted into the bone, neareft to the place where it moves upon another, overcome the greateft refiftance, and confequently act with [illegible].

[illegible] compofed of mufcles, which [illegible] are like red rib-bons, [illegible] have one of their ends fixed into [illegible] other of their ends into fome other bone. Thus, if we feel the great ham-ftring, [illegible] many mufcles, we fhall find [illegible] into the bones of the leg, [illegible] under the knee, and at the other end it runs [illegible] to be fixed in the great bone of the thigh. These mufcles being thus ftretched from one bone to another, have a wonderful power of [illegible] fhortening themfelves at pleafure; and when we choofe to put them into action, they fwell in the middle, fomewhat into the fhape of a [illegible]. As thefe mufcles thus contract, they muft neceffarily draw the two bones into which they are inferted their own way. The ham-ftring, when it contracts, for inſtance, draws the leg backward toward the thigh. When we want to make the limb ſtrait, there are muſcles inſerted under the fore-part of the knee, that, contracting, anſwer this purpoſe; while, in the mean time, the ham-ſtring ſuffers itſelf to be relaxed, in order to let the oppoſing muſcles take effect. This being underſtood, it will follow, that if we conſider any one of the bones, the arm bone, for inſtance, as a beam, and the muſcles that raiſe it and put it into motion as the power that agitates and works the inſtrument, the whole will give us the idea of the third kind of lever, where the prop is at one end, the weight to be ſuſtained at the other, and the ſtrength is applied between them both. Thus, for inſtance, if I ſtretch out my arm, the prop is in the joint of my ſhoulder, the weight is my hand, and the raiſing power is the muſcles, which are fixed into the arm bone near the ſhoulder, and go from thence to be inſerted into the bones of the trunk of my body. Now the nearer the ſhoulder theſe muſcles are inſerted into the arm bone, it is evident that the longer will be the lever againſt which they are to act, and conſequently the greater will appear the weight which they are to ſuſtain. To make this quite plain, ſuppoſe a ladder were laid flat on the ground; and ſuppoſe that I, ſtanding at one end, take the neareſt round of the ladder in both my hands, and thus pulling back, attempt to raiſe the fartheſt end, keeping the neareſt end ſtill ſteady to the ground. Would not this require immenſe ſtrength to effect? Pretty ſimilar is the force that the muſcles of the arm exert in raiſing the whole length of the arm, and the weight of the hand beſide. They are inſerted into the bone cloſe to the ſhoulder, and ſupport the whole length of the arm in the deſired direction. But, what is more, they do not only act upon the lever at ſo diſadvantageous a diſtance, but alſo they act upon in a direction the moſt oblique, and conſequently at a greater diſadvantage ſtill. Suppoſe I attempt to raiſe the diſtant end of the ladder, by pulling the round neareſt me; this, as I ſaid, will be very diſadvantageous: but ſuppoſe yet farther, that I ſhould firſt lie upon my back, and then, by drawing the next round to me of the ladder, I ſhould attempt to raiſe the diſtant end, the force that would be capable of effecting this would be incredible. Yet in this very manner it is that the muſcles of the ſhoulder act in raiſing the arm. They are not only inſerted at the greateſt diſtance from the weight, but they exert their power the moſt obliquely. The force they exert in keeping the hand and arm extended is great; the force they exert in keeping it extended, while the hand holds a weight of about twenty pounds, is aſtoniſhing. Some ſay that theſe muſcles, upon equal terms, would lift a weight ten thouſand times greater. What has been here ſaid of the muſcles of the arm, is true, in a greater or leſs degree, of all the muſcles of the body; ſo that this natural machine, thus faſhioned by the GREAT WORKMAN, is infinitely more powerful than any artificial machine that man could form, though it took up four times the ſpace.

The muſcles, as we ſaid, are ſupported by bones; theſe make altogether a ſingle pillar or column, which, though not perfectly ſtrait, but with about five different curvatures or bendings; yet when perfectly ballanced upon itſelf, would actually ſupport weights that would ſurpriſe the inexperienced. *La Hire* and *Deſaguliers* give us ſeveral accounts of the amazing weight ſome people have ſuſtained, when they were able to fix the pillar of their bones directly beneath it. The latter tells us of a German who ſhewed ſeveral feats of this kind at London, and who performed before the king and a part of the royal family. This man, being placed in a proper ſituation, with a belt which reſted upon his head and ſhoulders, and which was fixed below to a cannon of four thouſand weight, had the props which ſupported the cannon taken away, and, by fixing the pillar of his bones immoveably againſt the weight, ſupported it with ſeeming unconcern. There are few that have not ſeen thoſe men, who, catching a horſe by the tail, and placing themſelves in direct oppoſition to the animal's motion, have thus ſtopped the horſe, though whipped by his rider to proceed. In all ſuch caſes, the pillar of the bones is placed in direct oppoſition to the weight; they ſupport each other, and are prevented from rubbing or cracking by elaſtic griſtles fixed between each bone: theſe give way a little upon great preſſure, and reſtore themſelves almoſt inſtantly, when that is removed. Beſides theſe, there is a viſcous or ſlimy liquor that is ſqueezed in, as if from a ſponge, between every joint, and keeps theſe griſtles ſmooth, moiſt, and pliant. By means of this fluid all the joints move eaſily, and obey the impulſe of the muſcles with greater diſpatch. This fluid, and the griſtles (or cartilages, as anaomiſts call them) contribute not a little to the rength of the animal; they reſiſt the burden with n elaſtic force, and conform themſelves to the equality of the preſſure. In old age both are miniſhed, the griſtles become hard, and this quor (which anatomiſts call the ſynovia) is ueezed out in leſs quantities. The man, therere, in old age, becomes more ſtiff and more eak, chiefly upon this account, though partly cauſe his muſcles become then alſo more rigid, rd, and leſs fleſhy, as it is uſually called, as oſe who have eaten the fleſh of old animals know.

While we are at reſt, this fluid, or ſynovia abovementioned, oozes out between the joints, to fit them for the hour of action; when in exerciſe, the ends of the bones preſs againſt their griſtles, and theſe are ſeparated, in ſome meaſure, by the ſynovia or fluid. But there is ſtill another liquor, of an oily nature, which is preſſed at the ſame time from a ſmall fleſhy ſponge, placed in every joint; and this, mixing with the ſynovia, makes all ſupple and fit for buſineſs. I ſaid that the ſynovia, or viſcid liquor, oozes out between the joints in the hour of reſt; it is therefore in greateſt quantity between them in the morning, after we have taken our reſt the preceding night. So great is the quantity uſually ſeparated during ſleep between the joints of the back-bone, that ſome men are an inch taller in the morning than at night, and all men are ſomewhat taller, as may be quickly found by any who chuſe to make the experiment upon themſelves.

From what has been ſaid it appears, that, in carrying large burdens, the whole art conſiſts in keeping the column of the body as directly under the weight as poſſible, and the body as upright under the weight as we can: for if the center of gravity in the burden falls without this column, it will go near to fall; in fact, if the ſupporter were an inanimate machine, it would fall inevitably; but human power, in ſome meaſure, catches the center while yet beginning to deſcend, and reſtores the ballance which it had loſt the moment before. A man ballancing under a weight, reſembles one of thoſe people whom we uſually ſee walking upon a wire; they totter from ſide to ſide, for a moment loſe the center of gravity, but by throwing forward a limb, or diſtorting their bodies, they recover it again, to the great amuſement of every ſpectator. It is thus that he who rries a weight is obliged to act; on whatever rt of his body the weight is placed, he ballances by throwing as much of his column beneath the ad as he can. Could the weight be laid and enly ballanced upon him, ſtanding in his natural oſture, he could, as we obſerved before, ſupport n incredibly burden; and though he could not ove under what he could thus ſupport, yet he ould carry a much greater load, than if the urden were laid in any other manner. The weight man could ſupport, when thus evenly laid upon is ſhoulders, would break the back of the trongeſt horſe in the world. The reaſon is obious: in a man the whole column of bones ſupport he weight directly; in a horſe the weight is laid pon the column croſs-ways. The porters of onſtantinople are known to carry each a weight f nine hundred pounds: they lean upon a ſtaff hile loaded, and are unloaded in the ſame maner. The porters of Marſeilles in France are ound to carry yet more; their manner is this: four f them carry the burden between them, each aving a ſort of hood that covers the temples and ead down to the ſhoulders; to this is faſtened the ords that ſupport the frame or bier on which the eight is laid. By this contrivance the whole olumn of the bones acts directly againſt the load, nd an immenſe weight is thus ſuſtained.

We now, therefore, at length ſee the reaſon hy two men, carrying a load, can ſuſtain a greater eight than what either could ſeparately carry, if it ere divided into two equal parts. The reaſon is, hat two men can bear the load each more upright, nd with the column of their bones more oppoſed gainſt it.

As man bears a weight the better, the more pright he ſtands againſt it, it muſt follow neeſſarily, that the more bendings he makes in ſup-

porting

him a little below his hips. To the iron rings of the girdle a rope was fixed; the rope went between his legs, and through a ſlit of the prop. Several men, or even two horſes, could not by pulling move him out of his place: he ſeemed to pull with his hands, but theſe were of no advantage to him.

The ſame man having fixed a rope to a ſtrong poſt, paſſed it through a fixed iron eye, then hooked it on his girdle, and ſetting his feet againſt the poſt, near the ſaid eye, raiſed himſelf from the ground by the rope; which he broke by ſuddenly ſtretching out his legs, and fell backwards on a feather-bed, laid on the ground to catch him.

He lay down on the ground, with an anvil on his breaſt, upon which another man hammered with all his force a piece of iron with a ſledge-hammer.

He put his ſhoulders upon one chair, and his heels upon another, and ſupported one or two men ſtanding upon his belly, raiſing them up and down as he breathed; making with his back-bone, thighs, and legs, an arch; the abutment being on the chairs.

He lay down on the ground, a man ſtanding upon his knees; he then drew his heels towards his breech, and ſo raiſed his knees till they were perpendicular under the man; when he raiſed up his own body, and putting his arms about the man's legs, riſes with him, and ſets him down on a low table. This he ſometimes did with two men.

OF WHEEL CARRIAGES.

By what we have ſeen of man, conſidered as a machine, it is eaſy to obſerve that his frame is not pted to drawing carriages; while, on the contrary, in that of an animal upon all fours, the co-umn of whoſe bodies, and the ſituation of whoſe uſcles, act almoſt directly upon bodies placed hind them, they are perfectly fitted by nature r this kind of ſervice. Horſes are uſually em-loyed in the draft in England; mules, oxen, and her animals, are ſometimes uſed in other parts of e world. It might incur ridicule, if we pre-nded to inform the learner, that each of theſe ill draw a weight or carriage in proportion as ey are ſtrong: but notwithſtanding this is gene-lly the caſe, yet we are going to mention what ill ſeem a paradox; namely, that two horſes may e found, one ſtronger than the other, and alſo etter ſkilled in the draft, yet the weaker ſhall raw a weight, with the very ſame carriage, the ronger one could not remove! This will be ffected if the weakeſt horſe be the heavieſt; if he xceeds his antagoniſt more in weight than he is xceeded in ſtrength. I have before obſerved, that e weight re-acts and pulls back the horſe, as uch as the horſe acts upon the weight to pull it rward. Now the horſe has two ſources of power drawing the weight along; his ſtrength, which ives him velocity, and his weight, which, added, ives force; and it is evident, that the horſe which ath both in the greateſt proportion will draw the avieſt weights. If we ſhould imagine both orſes raiſing an equal weight from a deep pit, d this weight ſtill increaſed, ſo as to overcome eir ſtrength, it is plain that the lighteſt horſe ould ſooneſt be drawn in. We have ſeveral in-nces, in ordinary practice, of the great benefit increaſing the horſe's weight to promote his aft.

Horſes have little or no power to *draw*, but at they have from gravity, or *weight;* otherwiſe they could take no hold of the ground, and then they muſt ſlip, and draw nothing.

Common experience will inform you, that if a horſe is to convey a certain weight, he ought (that he may draw the better) have a proportionable weight on his back or ſhoulders. A horſe in a two-wheeled cart, in which there is a ton weight, when it is in an equilibrium will not be able to draw it; but when there are fifty or ſixty pounds bearing on his back, he will draw it with eaſe. If it be two or three ton, if he bears one hundred or two hundred pounds on his back, he will be able to draw the load, becauſe the wheels of a cart are very high.

When a horſe draws hard, he bends forward, and brings his breaſt nearer the ground; and then, if the wheels are very high, he is pulling the carriage againſt the ground.

A horſe tackled in a waggon will draw two or three tons weight, becauſe the line of traction is below his breaſt.

It is very common, when one horſe is drawing a heavy load, to ſee his fore-feet riſe from the ground, and he will nearly ſtand an end. It is uſual in this caſe to add a weight on his back, to keep his fore-feet down, by a perſon mounting on him, which will enable him to draw the load he could not move before.

The caſe is nearly the ſame in applying the ſtrength of a man in wheeling a load in a wheel-barrow. When moſt of the load lies on the wheel, he will ſlip, and not be able to get it forward; but then bring the weight nearer his arms, he will be able to drive it forward. In drawing a heavy garden-roll, if the axis of motion were even with that part of his body where his arms are extended, he could not be able to draw it along; but will draw it eaſily, if the line of traction is low.

In a loaded cart which hangs nearly in equilibrio, if two men were to take it by the ſhafts, then they would not be able to move it; but one of them in the ſhafts and the other behind the cart, puſhing the breech upward as well as forward, he lays a load on the firſt man's back, and ſo preſſing both the feet againſt the ground they will eaſily draw the load.

In a long team where only the hind horſe bears on his back, if you take off half the number and fix them to a lower point of traction, they will be able to move a much greater weight.

Sledges were probably the firſt machines uſed in carrying loads; we find them thus employed in *Homer*, in conveying wood for the funeral pile of *Patroclus*. There are ſome countries alſo, that preſerve their uſe to this day. However, men early began to find how much more eaſily a machine could be drawn upon a rough road, that run upon wheels, than one that thus went with a ſliding motion. And indeed, if all ſurfaces were ſmooth and even, bodies could be drawn with as much eaſe upon a ſledge as upon wheels; and in *Holland*, *Lapland*, and other countries, they uſe ſledges upon the ſmooth ſurface of the ice; for as every ſurface upon which we travel is uſually rough, wheels have been made uſe of, which rub leſs againſt the inequalities than ſledges would do. In fact, wheels would not turn at all upon ice, if it were perfectly ſmooth; for the cauſe of the wheels turning upon a common road, is the obſtacles it continually meets. For if we ſuppoſe the wheels to be lifted from the ground, and carried along in the air, the wheels in this caſe would not turn at all, for there would be nothing to put any part into motion rather than another; in the ſame manner, if they were carried along upon perfectly ſmooth ice, they would meet nothing to give a beginning to the circulatory motion, and all their parts would reſt equally alike.

But

unleſs the wheel moves round. And th
that the obſtacles in the rough road cauſe
culatory motion in the wheel.

The *utility of wheels* ariſes therefo
their turning about their axis, the reſiſtanc
from friction is very much diminiſhed,
draft is thereby rendered more eaſy; and
find by experiment that it requires conſider
force to draw a carriage when the wheels
to turn about their axis, than when they are
together and cannot turn. According to I-
a carriage with four wheels will be drawn w
times as ſmall an effort as one that ſlide
ſame ſurface in a ſledge. From the foreg
periment it not only appears that the fr
very much leſſened, but that this diminut
not ariſe from the wheels touching the pla
few points, but to their rotation on their a

A ſledge paſſing over a plane unde
friction, or rubbing of it's parts againſt th
equal to the diſtance through which it mov
if an axis be applied whoſe circumferenc
inches, and on that a wheel be placed wh

ade but one revolution in the ſame time, there as been only a ſliding of the parts equal to the ircumference of the hole in the nave here ſupoſed to be about ſix inches, ſo that the friction is eſſened about as one to thirty-ſix; beſides, the advantage gained by confining it to ſo ſmall a ſurface, whereby the parts are more eaſily kept ſmooth and fitted to each other, and ſubſtances applied and retained to leſſen the remaining friction.*

By the application of wheels to a carriage, *the friction is leſſened in proportion of the diameters of the axis, and concave part of the naves to thoſe of the wheels.*

When a carriage is drawn up hill, or any regular plane aſcent without wheels, you have not only the friction to overcome, but the power muſt alſo be ſufficient to overcome that proportion of the weight of the carriage, that the perpendicular part of the inclined plane bears to that portion of the plane.

Wheels applied to a carriage moving up a regular plane of aſcent appear only to act as removing the friction, for though they may be conſidered as levers, yet as each arm of the lever is lengthened in proportion to the ſize of the wheels, the power will be only augmented as far as the aſcent can be conſidered as a mechanical power for raiſing the wheels, carriage, &c. to the top of the hill.

Large wheels have the advantage of ſmall ones in overcoming obſtacles, becauſe they act as levers in proportion to their ſizes. That in general the center of gravity ſhould be as near as may be to the axis of the wheel; and where ſafety is particularly conſidered, the nearer that center is to the ground the better.

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* Arſtice's Remarks on the comparative Advantages of Wheel Carriages, p. 21, 40, 41, 42, &c.

If the ſuſpenſion be below and the body i turned forwards, (as is the caſe with two wheel carriages deſcending hills) then will the great part of the weight be thrown before the axis; a muſt be partly borne up by the horſe that draws; in aſcending, the ſame proportion will be thrown backwards and tend to lift the animal. If th body be ſuſpended above the center of gravity, th diſadvantages will be equal, but the effect will b reverſed.

The lateſt experiments on this ſubject have been made by the Rev. Mr. Vince. Some reſults thereof, which have been publiſhed in his excellent "Plan of a Courſe of Lectures on the Principles of Natural Philoſophy," I ſhall now lay before you; beſides theſe, there are ſeveral curious obſervations on this ſubject by Mr. L. Edgworth, publiſhed in the "Tranſactions of the Royal Iriſh Academy," which are well worth your attention, of which, however, I ſhall only mention that which relates to the uſe of ſprings when applied to carriages.

MR. VINCE ON WHEEL-CARRIAGES, ON PLAIN HARD GROUND.

If the wheels be all equal and narrow, it requires the ſame weight to draw the carriage, whether it be loaded before or behind.

If broad wheels be put on of the ſame ſize and weight, it requires the ſame weight to draw the carriage as for the narrow wheels, at whatever part it is loaded.

If two wheels be low and two high, it requires a greater weight to draw the carriage than when all are high.

In this caſe it makes no ſenſible difference which go before. The common opinion therefore

that

hat the high wheels drive on the lower when they go forward is not true.

If the wheels be all equal, it requires a greater weight to draw the carriage, the leſs the wheels are.

The diſadvantage of ſmall wheels ariſes from hence, that the reſiſtance of the ground, which turns the wheels about, more eaſily overcomes the friction at the axle in a large than a ſmall wheel, becauſe it acts at a greater diſtance. For the mechanical advantage of wheels is, that the reſiſtance which muſt be overcome by a force more than equivalent to it if the wheels could not turn, is overcome by a leſs force in the proportion of the radius of the wheel to the radius of the axle, when the wheels do turn. Hence the diſadvantage of laying the load upon the low wheels, as it increaſes the friction where there is the leaſt power to overcome it. Where the load is but ſmall, and conſequently the friction but ſmall, there is but a ſmall difference between the ſmall and large wheels; but when the load is great the difference becomes conſiderable.

ON HARD GROUND WITH OBSTACLES.

If W be the weight of the carriage, and the center of gravity be in the middle; alſo if $r =$ the radius of the wheel and $x =$ the height of the obſtacle, then the power P acting parallel to the horizon which is juſt ſufficient to ballance the carriage at the obſtacle without drawing it over $= \frac{W\times\sqrt{2rx-x^2}}{2r-2x}$.

For the power may be conceived to be drawing a weight up an inclined plane, which is a tangent to the circle at the point where it touches the obſtacle; and as when that end riſes, the other reſts upon the horizontal plane, the power has to elevate a weight only equal to $\frac{1}{2}W$.

Experiments of this kind are ſubject to inaccuracies which cannot be accounted for. The power will ſometimes hang for ſome time without moving the carriage, and then it will ſuddenly draw the carriage over the obſtacle. Sometimes there will be a difference of half an ounce out of about ten ounces in drawing the ſame carriage over the ſame obſtacle, although every care is taken to have all the circumſtances accurately the ſame. Many of the experiments however anſwer very nearly to the theory, nor do any of them differ from it very materially.

The uſe of high wheels in going over obſtacles is very manifeſt from this propoſition, and as carriages are continually going over obſtacles, high wheels will always have the advantage. Moreover in ſinking into holes they have a double advantage, firſt, they do not ſink ſo deep as low ones would; and ſecondly, after ſinking, they aſcend again with leſs power. As, when the center of gravity is in the middle of the carriage, the power has but half it's weight to elevate in going over an obſtacle, therefore when the load is not in the middle, it throws the center of gravity towards one end, and therefore when that end goes over an obſtacle the power has more than half the weight to raiſe, the preſſure upon each wheel being inverſely as the diſtance of the center of gravity from them. Hence every carriage ſhould be loaded moſt towards the higheſt wheels, by which means leſs than half the weight will be thrown upon the lower wheels, and thus each pair of wheels may be made to require the ſame power to draw them over an obſtacle. The ſame power, however, that may be neceſſary for one obſtacle will not be ſufficient for another.

If the height of the obſtacle be inconſiderable in a reſpect to the radius of the wheel, which is the aſe with the common obſtacles, as ſtones, &c. hich carriages uſually meet with, then $P = W \times \sqrt{\frac{2r}{x}}$. Now as each pair of wheels has the ſame bſtacles to go over, x is given, and that P may be iven, or that it may require the ſame power for ach pair, W muſt vary as $\sqrt{r}$; now the weight upported by each wheel is inverſely as it's diſtance rom the center of gravity. Hence to overcome mall obſtacles, the diſtance of the center of gravity from the great wheels; it's diſtance from the mall : : the ſquare root of the radius of the ſmall wheel : the ſquare root of the radius of the large wheel. The radii of the wheels of a common waggon are about 5 ft. 8 in. and 4 ft. 8 in. and he diſtance of the wheels, when narrow, about 5 ft. 6 in.; hence the center of gravity of the oad of a waggon ought to be about 3, 6 in. nearer to he higher than to the lower wheels. For a broad wheel waggon, where the diſtance of the wheels is about 7 ft. 10 in. the center of gravity ought to be about 4, 2 in. nearer to the higher than to the ower.

It appears alſo that when W and x are given and x is very ſmall, P varies inverſely as the ſquare root of the radius of the wheel. Hence the advantage of a wheel to overcome a ſmall obſtacle varies as the ſquare root of the radius of the wheel. This reſiſtance of the obſtacle cauſes the wheel to turn, but this reſiſtance is not friction; for friction ariſes from the rubbing of the parts of one body againſt thoſe of another, whereas there the wheel only turns upon a point; the friction therefore only takes place at the axle, where the parts rub one againſt another. There is therefore no friction at the ground, unleſs when the wheels ſlide, which is the caſe when they are chained together, which is frequently done to prevent them from running too faſt down a hill.

UPON SAND.

It requires a leſs force to draw a narrow than a broad wheel carriage upon ſand.

The diſadvantage of the broad wheels ſeem to ariſe from their driving the ſand before them.

If two wheels be high and two low, it requires a greater force to draw the carriage than when all the wheels are high.

If all the wheels be low, it requires a greater force to draw the carriage than in the laſt caſe.

In all theſe caſes it requires a leſs force to draw the carriage when loaded behind than before.

Whatever permits the load to riſe gradually over an obſtacle, without obſtructing the velocity of the carriage, will tend to facilitate it's draught, and the application of ſprings has this effect to a very conſiderable degree; the ſame weight of four pounds being drawn over the ſame obſtacles, when ſprings were put between the load and the carriage, by four pounds inſtead of fourteen. This remarkable difference points out the great advantage of ſprings in rough roads, an advantage which might be obtained for heavy waggons as well as for other carriages, by a judicious application of the ſame means.

It appears from the Memoirs of the French Academy, that the idea of applying ſprings to carriages had occurred to M. Thomas, in the year 1703, who has given a drawing of a carriage conſtructed upon this principle many years before it was attempted to be put in execution. So little expectation had he of ſucceſs, that he expreſsly mentions it as a theory which could not be reduced to practice; he had, however, no notion of applying ſprings to facilitate the draught, but merely for the convenience of the rider; and I apprehend that it is not at preſent commonly imagined that ſprings are advantageous for this purpoſe; nor would it at firſt ſight appear credible, that, upon a rough paved road, ſuch as are common in Cheſhire and other parts of England, a pair of horſes could draw a carriage mounted upon ſprings with greater eaſe and expedition than four could draw the ſame carriage if the ſprings and braces were removed, and the carriage bolted faſt down to the perch.

The reaſon why ſprings ſo much facilitate the draught of carriages ſeems to be, not only that they allow the wheels to paſs more gradually over the obſtacles, but that by their elaſticity they make the carriage bound upwards every moment for a ſmall way; thus it's gravity is for that moment in a great meaſure counteracted, and the progreſſive motion which it has already acquired is at liberty to act more freely in puſhing it forward; for were it poſſible very ſuddenly to take away the horſes from a carriage mounted on ſprings, and moving with conſiderable velocity, it would continue for ſome time to move of itſelf; the weight in this caſe acting as a fly upon any mechanical engine, by means of which the machine accumulates a certain quantity of power, and will keep itſelf in motion for a conſiderable time after the hand is taken away from it. The weight of all carriages indeed has ſome effect of this kind, otherwiſe the draught would require an intolerable exertion of ſtrength; and it is to be obſerved, that this tendency to proceed in the direction in which it is once ſet a going, is remarkable in all great quantities of matter, and very perceptible even when weights are pulled directly upward; for in raiſing great weights by a crane, the burden is lifted with conſiderable more eaſe when near the top than at bottom, even after making every neceſſary allowance for the weight of the rope.

I have now finiſhed the lectures on mechanics, a ſcience of whoſe importance you cannot be ignorant, as it is to the *manufacturer* and the *merchant* that this nation owes it's power and glory. The manufacturer ſupplies the merchant, and the merchant ſupplies the world with all it's wealth. It is thus that induſtry is promoted, arts invented and improved, commerce extended, ſuperfluities mutually vended, and wants mutually ſupplied; that each man becomes a uſeful member of ſociety; that country is tied to country, and clime to clime; that the remoteſt regions are brought to neighbourhood and converſe. It is thus the labour of individuals knits into one family, and weaves into one web the affinity and brotherhood of mankind.

Manufacturers bear ſo intimate a relation to the *mechanical powers*, as to be incapable of ſubſiſting in any degree of vigour without their ſupport; the operations would be tedious, expenſive, and imperfect, if performed by the mere efforts of human ſtrength or manual ſkill, unaſſiſted by mechanical aid. The mechanic powers facilitate their performance, and render their productions more complete.

Moſt of our manufactures are, under providence, entirely dependent on our machines. Of the importance of the ſteam engine, and the application of it's active and potent principles to the brewery; to machines for ſpinning cotton and grinding corn, &c. &c. you are well acquainted, and muſt therefore be ſenſible of the importance of mechanical knowledge, which will be of the higheſt value as long as *induſtry* and *commerce* are the natural, the living, the never failing fountains, from whence alone the wealth of this world can be taught to flow.

Dr. Smith in his "*Wealth of Nations,*" has ſhewn that the productive powers of labour, and the greater part of the *ſkill*, *dexterity*, or *judgment* with which it is any where directed or applied, ſeems to have been the effects of the *diviſion* of labour: what is the work of one man in a rude ſtate of ſociety being generally that of ſeveral in an improved ſtate. To make this more eaſily underſtood, by conſidering ſome particular manufacture, he inſtances that of a pin-maker; a workman not educated to this buſineſs, nor acquainted with the *machinery* uſed in it, which the diviſion of labour has rendered neceſſary, could ſcarce, perhaps with his utmoſt induſtry, make twenty pins in a day. But in the way which this buſineſs is now carried on, not only the *whole work* is a peculiar trade, but it is divided into a number of branches, of which the greater part are likewiſe peculiar trades.

One man draws out the wire, another ſtraitens it, a third cuts it, a fourth points it, a fifth grinds it's top for receiving the head; to make the head requires two or three diſtinct operations; to put it on is a peculiar buſineſs, to whiten the pins is another; it is even a trade by itſelf to put it into paper. And the important buſineſs of making a pin is in this manner divided into about eighteen diſtinct operations, which in ſome manufactories are all performed by diſtinct hands, though in others the ſame man will perform two or three of them. Dr. S. mentions a ſmall manufactory where ten men only were employed, and where ſome of them conſequently performed two or three diſtinct operations; but though they were poor, and therefore but indifferently accommodated with the neceſſary machinery, they could, when they exerted themſelves, make among them about twelve pounds of pins in a day. There are in a pound upward of 4000 pins of a middling ſize, they could therefore make among them upwards of 48000 pins in a day; each perſon therefore making a tenth part of 48000, might be conſidered as making 4800 pins a day. But if they had all wrought ſeparately, and independantly, and without having been educated to this peculiar buſineſs, they certainly could not each of them have made twenty pins a day, perhaps not one, that is certainly not the 240th, perhaps not the 4800 part of what they are at preſent capable of performing, in conſequence of a proper diviſion and combination of their different operations.

By this great increaſe in the quantity of work, which is in conſequence of the diviſion of labour, the ſame number of people are capable of performing is owing to three different circumſtances: 1. An *increaſe of dexterity* in every particular workman. 2. To the *ſaving of time*, which is commonly loſt in paſſing from one ſpecies of work to another. 3. To the invention of a great number of *machines*, which facilitate and abridge labour, and enable one man to do the work of many.

This view of the advantages of mechanics points out clearly the difference in the order of Providence between man and the brute creation. "In every foreſt, in every field, GOD has ſpread the carpet, and prepared the repaſt for thoſe whom he has not inſtructed to prepare it for themſelves. To *man* alone he gave *reaſon*, *invention*, and a *ſocial* nature; he gave him *weakneſſes* and *wants* as a fertile though humble bed, wherein he ſowed the ſeeds of every human virtue. By thoſe weakneſſes and wants he compells him to aſſociate; and from ſociety he derives all the conjugal, paternal, and filial endearments; the friend, the neighbour, the citizen, countryman, and all the charities that unite the great brotherhood of man.

"God ſuffers not any man, and rarely any nation to be ſufficient to itſelf, or of ability to ſupply it's own occaſions; the wealthieſt, the ſtrongeſt, the wiſeſt individual, though of power to extend his ſervice through his country and through the world, cannot ſingly provide for his perſonal ſubſiſtence.

Thus man, who, in himſelf, is the moſt impotent and pitiable of all living creatures, becomes the moſt powerful and formidable through community; from his *weakneſs* he gathers *ſtrength*, and from *wants* he gathers *plenty*. For here, and here alone, GOD hath laid the foundation of all the wealth and dominion that ever roſe upon earth. The innumerable wants, infirmities, and diſeaſes that are incident to human nature demand an innumerable proviſion from the various arts, ſciences, manufactories, and occupations that are exerciſed and cultivated throughout the earth; for from theſe alone ariſes the univerſal wealth of the world; whatever is neceſſary, uſeful, commodious; whatever conduces to the convenience, delight, or happineſs of mankind. Hence the buzz of wheels, reels, and looms; the ſound of hammers, files, and forges; the ſhouts of vintage, and the ſongs of harveſt.

Though man's life conſiſteth not in the abundance of his poſſeſſions, yet induſtry which is the natural parent of opulence, is as well a bleſſing as a duty to man, ever ſince he was appointed to *earn his bread with the ſweat of his brow*. Many temporal benefits follow in the train of induſtry, it's works are the works of peace, and it tends to open the avenues where the virtues may walk; and all legiſlators are called upon to encourage the mechanic arts, that they may promote ingenuity and industry, and enable the manufacturer to perſevere in his labour. When the good houſeholder walked out to the market-place, and found labourers loitering there, when it was now toward the evening, he aſked them, *Why ſtand ye here idle?* and *when they anſwered, becauſe no man hath hired or given us employment,* he took this for a ſufficient apology; he had compaſſion upon them, and he ſupplied them with the divineſt of all kinds of charity, *the means of earning their own bread.*"

LECTURE

LECTURE XXXIII.

HYDROSTATICS.

cience deſcribing the mechanical affec-
of fluids, and their efficacy in the produc-
oſe natural phenomena of which they are
diate cauſes, is properly and uſually called
n writers *hydrodynamics*, and is divided
branches; *hydroſtatics*, whoſe object
ation between the weight of water and
lies; and *hydraulics*, which treats of the
f water through pipes, conduits, &c.
ics is now uſed by us with greater latitude
the ſcience deſcribing the properties of
but principally thoſe of water; and ex-
the motions thereof, whether in pipes,
phons, fire-engines, jet d'eaus, &c. and I
avour to exhibit them to the eye and to
rſtanding in the moſt eaſy and familiar

principles of all knowledge are founded
the mind of man, either animated by de-
reſſed by neceſſity, puts in action it's va-
rgies, and unfolds the ſeeds of knowledge.
n right when we apply to any ſubject only
as which are derived from it's real na-
we fall into every kind of error, when
judice or any other cauſe we conclude
e have reaſoned, reaſon before we know,
me that we know before we have exa-
The more ſimple the object is in itſelf,

the ſooner the mind diſcovers it's various relations, and is enabled to riſe from one truth to another till it reaches thoſe that are the moſt abſtract. Hence it is that greater progreſs has been made in geometry than in any other ſciences purely intellectual, becauſe the ſuppoſitions are few and ſimple, and only abſtract properties are conſidered; but when material objects are conſidered, of whoſe elementary parts we know neither the ſize nor the form, nor the laws by which they are actuated, and yet endeavour to foretel their effects, to calculate their efforts, and to determine their action, nature ſhews herſelf independent, and faithful to the laws preſcribed to her, and of which we are ignorant; ſhe contradicts our views, diſconcerts our projects, and renders our efforts uſeleſs.

It is thus in hydraulics; experience contradicts theory, and the ableſt mathematicians, a Newton, a Bernouilli, and a D'Alembert have not been able to make them coincide. Hence our knowledge of this ſubject is very limited; for though during a courſe of ages many men of the greateſt abilities have endeavoured to inveſtigate this ſubject, it is ſtill enveloped in ignorance, and ſurrounded with difficulties. We are ſtill ignorant of the true laws which govern the motions of water; even aſſiſted by experiments for 150 years, we can hardly yet be ſaid to have determined either the time, the quantity, or the actual velocity with which water ſpouts from a given aperture. We know ſtill leſs concerning the uniform motion of thoſe rivers and rivulets which water the ſurface of the earth. That you may form a truer idea of the little we know, I ſhall give you a ſhort ſketch of ſome of thoſe things of which we are ignorant.

Were it neceſſary to appreciate the velocity of a river, whoſe breadth, and depth, and inclination are known, to determine the height it's waters will be raiſed by the acceſſion of another river, or how much they will be lowered by a cut from it; to fix the inclination neceſſary to give to the waters of an aqueduct a certain velocity, or determine the capacity of the bed with a given inclination that ſhall be ſufficient to ſupply a certain town with water; ſo to trace the windings for a river, that it may not endeavour to change the bed in which it has been incloſed; to calculate the water expended by a conduit pipe, where the length, diameter, and charge are given; to determine how much the waters of a river, a canal, &c. will be raiſed by a bridge, a lock, &c. and how far the return of the water will be ſenſible; to aſſign the beſt form for the mouth of canals and rivers; to find the moſt advantageous figures for ſhips and boats, that they may cleave the water, and move therein with the leaſt effort; to calculate the force neceſſary to move a body floating on the water; all theſe queſtions, and an infinite number more of the ſame kind, cannot be ſolved in the preſent ſtate of this ſcience. It ſeems almoſt incredible, we are ſtill almoſt ignorant what the impulſe of water ſtriking directly againſt a plane ſurface is equal to, conſequently more ſo when it impinges againſt convex and other curved ſurfaces.

Nay, it is not clear, when we conſider the immenſe aqueducts, &c. of the ancients, whether they did not know more than we do on theſe ſubjects. You have already ſeen that their knowledge of mechanics was greater than is generally believed, and to *Archimedes* we are indebted for the general principles of hydroſtatical knowledge; he even goes ſo far in one of his works as to eſtabliſh, that any point whatſoever of a fluid maſs is equally preſſed in all directions, and examines the conditions neceſſary to make a body floating on a fluid take and preſerve an equilibrium of ſituation.

One hundred years after him, Cteſibius and Hero of Alexandria invented ſeveral ingenious hydraulic engines; among theſe we may reckon the fountain of compreſſion, ſtill known by the name of Hero's fountain, and the bent ſyphon ſo uſeful for decanting liquors: thus, without knowing diſtinctly the ſpring and weight of the air, they employed theſe agents with ſucceſs.

S. I. Frontinus appears to be the firſt who has given us any account of the motion of fluids; he was inſpector of the public fountains under the emperors Nerva and Trajan; and in a work on this ſubject, has made ſome very valuable remarks, and communicated ſome excellent obſervations. From his time to that of Benedict Caſtelli, the friend of Galileo, we find no traces of any further progreſs. The neceſſity of guarding againſt the continual damages from the overflowings of the rivers in Italy, induced *Urban* the Eighth, who had invited *Caſtelli* to Rome as a teacher of the mathematics, to requeſt he would apply himſelf to this ſubject; the reſult of his inquiries is contained in his treatiſe, entitled, *Della meſura dell acque correnti*: in this he was ably followed by *Guglielmini Friſi*, &c. But ſtill we ſcarcely find one writer who acquieſces in the ſolution of another; even the great *Newton*, who paid particular attention to ſome of theſe ſubjects, is not very conſiſtent with himſelf. Here, therefore, much remains for future experiments, in order that new axioms may be eſtabliſhed, new inventions found; thus the great volume of nature is calculated by the OMNISCIENCE OF IT'S AUTHOR to afford ſcope to the virtuous, and honourable employment to ſages and philoſophers, till they are removed to a more perfect ſyſtem, where the FIRST will take place of SECOND cauſes, when the film which is ſpread over the corporeal eye will be removed, new objects preſented, and new ſcenes diſcloſed under the aſpect and illumination of a brighter SUN.

OF FLUIDITY.

A fluid is generally defined to be a body whoſe parts are ſo looſely connected together, that they eaſily yield to any force impreſſed upon them, and move freely amongſt each other. In this ſenſe fire, air, mercury, water, &c. are conſidered as fluids.

In almoſt every phyſical ſpeculation, wherever experiment can reach, the ſubject will admit of ſome illuſtration; where that is denied, the reaſonings are in general vain and conjectural. We do not know the form of the parts of which fluids are compoſed, and can make no experiments to reduce them into the primary particles of which they are compoſed.

There is nothing more different in accuracy and truth, than that apprehenſion which is adequate to the purpoſes of the vulgar, and that which ought to ſatisfy the inveſtigation of a philoſopher. Thus there is nothing more obvious to the vulgar han *fluidity*, yet the philoſopher finds it a property difficult to be conceived, and which he could not give credit to, if it was not rendered familiar to him by cuſtom and experience; it is a phyſical phenomenon which has not yet been explained, and of which it is very difficult to give a clear account. How, indeed, can we comprehend, that a material and incompreſſible ſubſtance can be compoſed of parts ſo elementary, ſo moveable among themelves, and yet with ſo little adherence, as to aſſume mmediately the form of any veſſel into which it is poured; that it's ſurface is always parallel to the orizon, or perfectly level; that in ſyphons, or when agitated by the wind, it makes iſochrone vi-

brations,

brations, or undulations like a pendulum; that it runs off where favoured by the ſmalleſt deſcent, &c. &c.

Fluidity is cauſed by a certain degree of fire, which, when employed for this purpoſe, diſappears with reſpect to any other ſenſible or perceptible effect. It does not dilate the volume, but reſiſts the particular attachment of the parts.

Some have endeavoured to give mechanical ideas of a *fluid body*, by comparing it to a heap of ſand; but the impoſſibility of giving fluidity by any kind of mechanical comminution, will appear by conſidering two of the circumſtances neceſſary to conſtitute a fluid body.

1. That the parts, notwithſtanding the greateſt compreſſion, may be moved, in relation to each other, with the ſmalleſt conceivable force, or will give *no ſenſible reſiſtance* to motion within the maſs in any direction.

2. That the parts ſhall gravitate to each other, whereby there is a conſtant tendency to arrange themſelves about a common center, and form a ſpherical body; which, as the parts do not reſiſt motion, is eaſily executed in ſmall bodies. Hence the appearance of drops always takes place when a fluid is in proper circumſtances.

Let us now ſee how far theſe qualities may be procured by mechanical operations, even executed without thoſe imperfections that neceſſarily attend human performance.

A body of ſand, the particles of which ſhould be perfectly ſpherical and poliſhed, or ſmooth, would only imitate a fluid in being able to ſpread itſelf upon a ſmooth plane, inſtead of lying in a heap, but would poſſeſs neither of the two qualities eſſential to a fluid body.

For a heap of ſpherical bodies, if compreſſed, could not move by relation to each other, except by a force ſufficient to ballance that by which, in this caſe, they are neceſſarily retained in their places. Neither can the parts of the ſuppoſed body of ſand cohere, either to themſelves, or to other bodies, in the manner of fluids, as in each particle the maſs of gravitating matter muſt be great in proportion to the point of contact by which they ſhould cohere. If the coheſion of the particles of ſand increaſed, the ſpreading quality would be diminiſhed.

Many other differences might be pointed out; but ſuppoſing every thing elſe favourable to the mechanical theory, yet ſtill there would remain to be explained the operation of fire, which is ſo eſſential to fluidity. This would lead us too far, as it would render it neceſſary for us to inveſtigate the nature of that reſiſtance by which the figure of bodies is preſerved in their hardneſs.

By fire hard bodies are made ſoft; but it is not properly that portion of looſe fire which augments the volume of bodies that renders them fluid: their fluidity is occaſioned by *a certain quantity of fire, which then diſappears, with regard to any other ſenſible or perceptible effect.*

OF THE GRAVITY OF THE PARTICLES OF FLUIDS, AND IT'S EFFECTS ON THE FLUIDS THEMSELVES.

Though no one finds any difficulty in allowing that water and other fluids are really ponderous, and do actually gravitate when conſidered as a whole body, being convinced by their own ſenſes, that a veſſel weighs leſs when empty, than when filled with any fluid, and weighs heavier the more it contains; yet, in the early times of philoſophy, there were thoſe that believed fluids did not gravitate *in proprio loco*, as they termed it; that is, when immerſed in the ſame, or a different fluid. A ſimple experiment will ſhew you that they were miſtaken, and that fluids loſe nothing of their weight *in proprio loco.* Here is a hollow glaſs ball, *fig.* 5, *pl.* 2, furniſhed with a braſs ſtop-cock, and made ſo heavy as to ſink in water. Exhauſt it of it's air, and then ſhut the cock. I exhauſt the air from it, to give room to a quantity of water equal in bulk to the exhauſted air. Suſpend it now from the end of this ballance, ſo that the bottle and the ſtop-cock may be under the ſurface of the water in the jar, and then counterpoiſe it by a weight in the oppoſite ſcale. Now open the cock, that the water may run into the bottle, and the water will ruſh in, and the ball will preponderate, and bear down the beam on which it hangs; clearly proving, *that the parts of water retain their gravity in water,* ſo as to preſs and bear down upon the parts beneath them, otherwiſe the phial would not become heavier upon the admiſſion of the water; and you will find that the ball over-ballances the counterpoiſe, as much as the weight of the quantity of water in the ball.

To facilitate the explanation of hydroſtatic phenomena, it has been uſual for the writers on this ſubject to conſider the fluid in a veſſel as cut into ſeveral horizontal planes, or imaginary ſurfaces, and to conſiſt of a vaſt number of ſmall, equal, lubricous, ſpherical globules. Thus, *fig.* 2, *pl.* 1, A B C D may repreſent a veſſel conſiſting of ſuch globules, a b, c d, e f, imaginary horizontal ſurfaces. Beſides this imaginary horizontal diviſion of a fluid, they often conſider it as divided into perpendicular columns, from the top to the bottom of the fluid, as at *fig.* 3, *pl.* 1.

Though fluids are ſubject to the laws of gravity as well as ſolids, yet their fluidity occaſions ſome peculiarities neceſſary to be noticed. The parts of a ſolid are ſo connected together as to form but one and the ſame whole; their effort is as it were concentrated in a ſingle point, called the center of gravity. This is not the caſe with fluids; the particles here are all independent of each other, are extremely moveable, yielding to the leaſt effort that tends to ſeparate the one from the other.

The parts of a fluid gravitate independently of each other. This is a natural conſequence of their fluidity, or their not adhering together; whereas the particles of a ſolid cohere together, and gravitate as one maſs. It is clear, from this principle, that if a hole be made in a veſſel full of water, the power neceſſary to prevent the fluid from running out, muſt be able to overcome the column of the fluid preſſing on the hole, and that the weight to be overcome is the ſame, whether there is only this column of the fluid acting on the part ſtopping the hole, or whether the veſſel be full.

This will be rendered clearer by an experiment. This cylindrical glaſs veſſel (A B C D, *fig.* 1. *pl.* 1, *Hydroſtatics,*) has a hole at bottom; a cylindrical tube of braſs paſſes through, and is fitted to this hole; a ſmall piſton, or plug, is fitted to this tube; and being well greaſed, ſlides eaſily up and down; a long wire is fixed to this piſton, to be hooked on to one arm of the ballance E F. On the upper part of this ſhort tube I can occaſionally fit a glaſs tube, G H, which is exactly of the ſame diameter as the braſs tube, and of the ſame height with the large veſſel.

I fit the glaſs tube in it's place, and pour in water up to this mark. Now I ſhall put weights into the ſcale at the oppoſite arm of the ballance, till the piſton juſt begins to riſe; I then take away the glaſs tube, and fill the large veſſel with water to the ſame height, and you ſee that the ſame weight as before overcomes the preſſure. Now as the ſame weight overcomes the preſſure, whether a column of water be only the ſize of the piſton, or whether the veſſel be full of water, it is clear that particles of water exerciſe their gravity independent of each other; but if the maſs of water contained in the outer veſſel was changed into ice, to raiſe the piſton you muſt uſe a weight equal to the weight of the whole column of ice.

The ſurface of a fluid which is contained in an open veſſel, and free from all external impediments, *will be level*, or parallel to the horizon. No part of a fluid can ſtand higher than the reſt; for if any part be raiſed, it muſt deſcend by the force of gravity, and, in ſo doing, will ſpread and diffuſe itſelf till it is on a level with the other parts; for having gravity, and yielding eaſily to every impreſſion, they obey the force of gravity, and ſlip down till they come to a level.

As the gravity of the particles reduces the upper ſurface to a level, ſo likewiſe it occaſions a preſſure on the lower part, greater or leſs in proportion to their depths below the ſurface, each part containing a preſſure equal to the weight of all thoſe that lie above it; conſequently, the particles which are at equal depths below the ſurface are equally preſſed. In other words, as the upper ſurface of the fluid is parallel to the horizon, and as the lower parts ſuſtain the upper, and are preſſed by them, this preſſure will be in proportion to the incumbent matter, that is, *to the height of the fluid above the particle that is preſſed:* but as the upper ſurface of the fluid is parallel to the horizon, *all the points of any ſurface that you may conceive within the fluid, parallel to the horizon, are equally preſſed.* Should this equality of preſſure be at any time deſtroyed, and *there be a leſs preſſure on one part of the ſurface than on the other parts*, the fluid yielding any impreſſion, *this part will be moved, that is, will aſcend till the preſſure becomes equal.*

To confirm this by experiment, take this glaſs tube, open at both ends, and ſtopping one end with your finger, immerge the other in water. The water, you ſee, riſes in the tube; but the tube being full of air, while you keep your finger upon the orifice, the riſe is but ſmall; but if you take away your finger, that the air which is compreſſed may eſcape, the water will riſe up into the tube, and not be at reſt till it attains the ſame height with the external water.

Solids, you know, make no effort but in the direction of gravity, or perpendiculary downwards; *but fluids exert a force of preſſure equal to heir gravity, in all directions, and in all equally.* This follows from the nature of a fluid, for it's paricles yield to any impreſſion, and are eaſily moved; herefore no *drop* will remain in it's place, if, hilſt it be preſſed by a ſuperincumbent fluid, it be ot equally preſſed on all ſides, becauſe, being a uid itſelf, it will yield to every impreſſion, and egin to move, unleſs it be acted upon by equal orces, in all poſſible directions. But it cannot move, becauſe the ſurrounding drops reſiſt on all ides it's motion with the ſame force that it endeavours to move, and conſequently the drop muſt remain at reſt; and what is thus proved of one drop, holds equally true of all; conſequently *all the parts of a fluid, at equal depths below the ſurface, are preſſed equally in all directions.*

Take the ſeveral glaſs tubes, A, B, C, D, *fig.* 4, *pl.* 1, which are open at both ends; immerge them in water to the ſame depth, their upper orifice being ſtopped by the finger. Upon taking away the finger, the water will riſe to the ſame height in all the tubes, though it enters the lower end in very different directions: in A the preſſure is di-aſcend upwards, in B downwards, in C ſideways, and in D obliquely, but the preſſure is equal in each. If you pour a greater quantity of water into th veſſel, it will riſe equally in the tubes; *ſo th fluids preſs in all manner of directions, and that wi a force proportionable to their heights.*

The ſame experiment is perhaps rendere ſtill clearer by pouring ſome mercury into tube The tubes for this purpoſe are ſmaller than thoſe uſed in the former experiment: ſome of them a ſtrait, and others bent at various angles. Thoug the tubes are open at both ends, one of the extr mities ſhould be cloſed till after the immerſion, prevent the mercury from falling out.

On immerging the lower end of theſe tubes water, you will find the mercury aſcend toward t upper end of the tubes. It is to be remarked, co cerning this experiment, that whatever be t angles at which the tubes are bent, and howe they are inclined to the horizon, if before imm ſion the mercury in all the tubes be on a level, will continue ſo after immerſion, provided all tubes are immerſed to the ſame depth.

Conſequently, when it has been proved t the preſſures of a fluid are as the ſurface preſ and their depths from the ſurface of the incumb fluid, it will follow, that the preſſure of a flui not only propagated in all directions, but that quantities of the preſſure at the ſame depths, on a given ſurface, are equal in all directions.

On a curſory view of the ſubject, you conſider it as a kind of mechanical paradox, the preſſure of a fluid upward, or in a direction trary to that of gravity, ſhould be nothing than a conſequence of gravity itſelf; but it is eaſy to ſhew, from mechanical principles, th force acting in a given direction may comm cate preſſure through a number of interme

bo

[illegible]

[illegible]

T[illegible] the quantity, [illegible], when the height of the fluid, [illegible] area or surface pressed, remain the same, the action upon this surface will always be equal, however the figure of the veſſel be changed. In other words, the preſſure which the *bottom of the* [illegible] *the fluid* [illegible]*tained*

Now the ſame preſſure which would ſupport the water in ſuch a tube acts upon F E; but the re-action of F E downwards is equal to the action upwards againſt it: that is, E F keeps the water down with a force equal to that with which it endeavours to riſe, equal to the difference of weight between F E I and M N O R: and as F I ſuſtains both the weight of the water F E I, and the action or force with which the water is kept from riſing, but O R ſuſtains only the weight of water M N O R, the preſſure upon F I will be equal to the preſſure upon O R, and the ſame may be proved of any other column. Therefore the bottom of the cone is as much preſſed by the weight of water which fills the cone, and this re-action together, as the ſame bottom would be preſſed by the weight of as much water as would fill up the whole cylindrical ſpace C B F T; that is, *the preſſure upon the bottom of a conical veſſel, is equal to the preſſure upon the bottom of a cylindrical one of the ſame* BASE AND HEIGHT.

The ſame mode of reaſoning may be applied to the veſſel D B L P, *fig.* 8, *pl.* 1, which conſiſts of two cylindrical parts N M L P, a great cylinder at the bottom, and D B I V a leſſer one at the bottom. For the preſſure upon L P, when the veſſel is full of water, will be as great as if the veſſel was as wide at top as it is at bottom; that is, as great as it would be upon the ſame bottom L P, ſuppoſing the veſſel was an uniform cylinder, whoſe baſe was L P, and height L F.

L A, and O R, two equal drops at the ſame depth, are preſſed equally; and O R having as much water to ſuſtain, is as much preſſed as if the veſſel was an uniform cylinder. Therefore L A, or C P, or any other equal part at the bottom, and conſequently the whole bottom, is as much preſſed in one caſe as it would be in the other. Indeed L A or C P have leſs water to ſuſtain than O R;

O R; but the column N T L A preſſes upwards againſt N T with a force equal to the difference between this column and D B O R, or to the weight of as much water as would fill the ſpace F E N T; for if a hole was made at N T, and a tube, F E N T, ſoldered into it, the preſſure againſt the bottom of the tube would ſupport water in it to the height N T, the ſame height it ſtands at in the tube D B I V. Now as the re-action of N T downwards is equal to the action upwards againſt it, that is, the force with which N T keeps the water below it, down againſt L A, is equal to the force with which this water preſſes againſt N T.

L A is therefore preſſed down not only with the weight of the water N T L A, but likewiſe by the re-action of N T, which is equal to the weight of as much water as would fill F E N T, and make N T L A equal D B R O; from which it follows, that the weight and re-action together on L A, are equal to the weight on D B R O, by which O R is preſſed; and the ſame may be proved of every other equal portion of the whole bottom and cover, and therefore, by the weight and re-action, L P is as much preſſed as if it was the bottom of a cylindrical veſſel F H L P, having the ſame dimenſions at the top as at the bottom, and filled with water to the height L F.

Though the preſſure upon F T, *fig.* 6, *pl.* 1, is equal to the preſſure upon C D, when both veſſels are filled with water to the ſame perpendicular height; yet *if they were filled with ice, or any other ſolid ſubſtance,* inſtead of water, C D would be more preſſed than F T.

For C D, whether the veſſel be filled with ice or water, ſuſtains the whole weight of the body which reſts upon it, and no more; but F T, which,

beſides

beſides the weight M N F T, ſuſtains the re-action of the ſides M N F T, when the veſſel is filled with water, has *only* the weight to ſuſtain when it is filled with ice; for ice, or any other ſolid body, does not preſs upwards. This is a property, which, as it only ariſes from the nature of a fluid, belongs to fluids only; F T will therefore be only preſſed by the weight of the ice, and conſequently will be leſs preſſed than C D, in proportion as the cone is leſs than the cylinder, when their baſes and heights are equal.

For the ſame reaſon L P, *fig*. 8, *pl*. 1, if it were full of ice, would be as much leſs preſſed than when it is full of water, as the quantity of matter contained in the compound veſſel N M L P is leſs than the quantity of matter contained in a cylindrical veſſel, whoſe baſe is L P, and height L F.

The *ſecond caſe* of the propoſition is when the veſſel A B O R, *fig*. 9, *pl*. 1, is wider at top than bottom. For here alſo the preſſure of any fluid upon the bottom, O R, of it, is the ſame as in a cylindrical veſſel, S T O R, of an equal baſe, and filled with the ſame ſort of fluid to the ſame height.

For the bottom O R, in either caſe, ſuſtains juſt the ſame quantity of fluid, and conſequently the ſame quantity of matter. If it is the bottom of a cylinder, then it ſuſtains no more than the column S T O R, becauſe the veſſel holds no more. If it be the bottom of an inverted cone, as A B O R, then it ſuſtains only the ſame column; for though the veſſel holds more than this, yet all the reſt of the fluid is ſupported by the ſides A O, B R, and therefore does not preſs on the bottom.

Thus you ſee, that whether a veſſel be narrower or wider at the top than at the bottom, the preſſure upon the bottom is the ſame as in a cylindrical veſſel of the ſame baſe and height; for when it is narrower at the top than at the bottom, though it holds leſs water than the cylindrical one would, yet the preſſure is not leſs, becauſe the reaction of the ſides ſupplies the defect; and when it is wider at the top than at the bottom, though it holds more water than the cylindrical one would hold, yet the preſſure is not greater, becauſe the ſides ſupport the exceſs.

Let us now confirm by experiment, what I have endeavoured to render plain without it. The apparatus on the table, *fig.* 10, *pl.* 1, is deſigned for this purpoſe. It is ſometimes called the apparatus of *Paſchal*, ſometimes the apparatus for illuſtrating the *hydroſtatic paradox.* It conſiſts of three veſſels, *fig.* 11, *fig.* 12, and A B C D, *fig.* 10, each of which are of the ſame ſize at bottom, and of the ſame height, and may be ſcrewed alternately on the braſs barrel E F, *fig.* 10, in which a piſton ſlides up and down with eaſe. One of the veſſels, *fig.* 12, is cylindrical; the other, A B C D, *fig.* 10, is an inverted cone, wider at top than bottom; the third, *fig.* 11, is a tube ſcrewed to a plate, which makes the bottom the ſame ſize as that of the other two; it has a funnel at top, to prevent the water, in making the experiment, from ſplaſhing over.

I ſhall firſt ſcrew the cylindrical veſſel to the barrel, puſhing down the piſton as low as it will go, then hook the wire of the piſton to the rings from the ſhort ends of the ſteelyards G H, I K. Now pour water in the cylinder up to the mark in the inſide thereof, and find what weights, ſuſpended from the longer arms of the ſteelyard, will raiſe the piſton; then take the cylindrical veſſel from the barrel.

Subſtitute the veſſel A B C D, *fig.* 10, which is like an inverted cone, in place of the former; fill it with water to the mark, as before, and hook on the wire of the piſton to the ſteelyards; and though the quantity of water is now many times greater than what was in the cylinder, yet the ſame counterpoiſe will raiſe the piſton.

Take off the conical veſſel, and ſcrew on the tubular one; and though this holds a much ſmaller quantity than either of the former, ſtill it requires the ſame counterpoiſe.

The friction of the piſton being the ſame in every caſe, makes no alteration in the experiment.

To ſhew that the *lateral preſſure* is equal to the perpendicular preſſure upon a larger ſcale, and in a manner which relates more to the preceding experiment, here is an apparatus, *fig.* 5, *pl.* 1, with different tubes, that communicate with each other. The middle one is a large glaſs tube or cylinder, A B; the lower end is firmly cemented into a ſtrong braſs hoop; to the ſides of this hoop are ſoldered the braſs tubes G, H, into each of which a glaſs tube is cemented. One of theſe, E F, is parallel to the large glaſs veſſel A B; but the other, C D, is inclined thereto. The inclined tube is ſometimes furniſhed with a joint, that the inclination may be varied at pleaſure.

Pour water into the tube E F; this will run through G, into the larger veſſel A B, and riſe therein; and if you continue pouring water until it comes to any height therein, as I K, and then leave off, you will find that the ſurface of the water in the ſmall tubes E F, C D, is at the ſame height; the perpendicular altitude is the ſame in all the three tubes, however ſmall the one may be in proportion to the other. This experiment clearly proves, that the ſmall column of water ballances and ſupports the large column; which it could not do if the lateral preſſures at bottom were not equal to each other. Whatever be the inclination of the tube C D, ſtill the perpendicular altitude will be the ſame as that of the other tubes, though to that

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end the column of water muſt be much longer than thoſe in the upright tubes.

Hence it is evident, that a ſmall quantity of a fluid may, under certain circumſtances, counterballance any quantity of the ſame fluid.

Hence alſo it is evident, *that in tubes that have a communication, whether they be equal or unequal, ſhort or oblique, the fluid always riſes to the ſame height.* Conſequently water cannot be conveyed by means of a pipe that is laid into a reſervoir, to any place that is higher than the reſervoir.

It has been aſſerted, that the ancients were ignorant of this principle, and knew not the uſe of pipes for conveying water up hills: but this aſſertion is not true; they did know the uſe of pipes, but choſe to employ aqueducts in their ſtead, for reaſons we cannot now with certainty aſcertain.

Our next experiment proves, with great clearneſs, the hydroſtatical paradox, that very great weights may be ballanced by a very ſmall weight of water, without it's acting to any mechanical advantage; but, more particularly, it alſo proves, that it's preſſure upwards is equal to it's preſſure downwards, and all this even to thoſe who have no previous knowledge of hydroſtatical principles. The apparatus, *fig.* 1, *pl.* 2, conſiſts of two large thick boards, C D, E F, connected together by leather, like a pair of bellows; hence it is uſually called the *hydroſtatic bellows.* A long braſs pipe is fixed to the bottom board; ſo that water being poured in at the top, will paſs between the two boards. In the apparatus before you the boards are oval; the longeſt diameter is eighteen inches, the ſhorter one ſixteen inches. I have poured water enough into the bellows to keep the boards aſunder, and have put ſix half hundred weights on the top of the boards. I ſhall now pour water into the tube, to the height of three feet, and it will puſh up all the weights. Thus the water in the pipe, which weighs but a quarter of a pound, ſuſtains three hundred pounds weight. Take off the weights, and try, by preſſing upon the upper board, to force the water out at the upper tube; your ſtrength, you ſcarce ſufficient for the purpoſe. Thus you ſee c rly how great a preſſure upwards is exerted by the water.*

Upon this princi mathematicians aſſert, *that the ſame quantity o ter, however ſmall, may oduce a force equal to ny aſſignable one, by increaſing the height an e upon which it preſſes.* Dr. Goldſmith ving ſeen a ſtrong hogſhead ſplit by this means. A ſtrong, though ſmall tube of tin, twenty feet high, was inſerted in the bung-hole; water was poured in this to fill the hogſhead, and continued till it roſe within about a foot

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* *Fig.* 16, *pl.* 1, repreſents another inſtrument for proving that the preſſure of fluids is in proportion to their perpendicular heights, without any regard to their quantity.

A B C D is a box, at one end of which, as at *a*, is a groove from top to bottom, for receiving the upright glaſs tube I, which is bent to a right angle at the lower end (as at *fig.* 17); and to that end is tied the end of a large bladder (K, *fig.* 17), which lies in the bottom of the box. Over this bladder is laid the moveable board M, *fig.* 18, in which is fixed an upright wire. Leaden weights (N N, *fig.* 16), to the amount of ſixteen pounds, with holes in the middle, are put upon the wire, over the board, and preſs upon it with all their force.

The bar *p* is then put on, to ſecure the tube from falling, and keep it upright; and then the piece E F G is to be put on, to keep the weights in an horizontal poſition, there being a round hole at *e*. Within the box are four upright pins, to prevent the board at firſt from preſſing on the bladder.

Pour water into the tube at top; this will run into the bladder: and after the bladder has been filled up to the board, continue pouring water into the tube, and the upward preſſure of the fluid will raiſe the board with all the weight upon it, even though the bore of the tube ſhould be ſo ſmall that leſs than an ounce of water would fill it.

oot of the top of the tube; the hogſhead then urſt, and the water was ſcattered about with ncredible force.

As the bottom of a veſſel bears a preſſure pro- ortional to the height of the liquor, ſo likewiſe o thoſe parts of the ſides which are contiguous to he bottom, becauſe the preſſure of fluids is equal very way; and as the preſſure which the lower arts of a fluid ſuſtain from the weight of thoſe bove them exerts itſelf equally every way, and is ikewiſe proportional to the height of the incum- ent fluid, the ſides of a veſſel muſt every where ſuſ- ain a preſſure proportional to their diſtance from the pper ſurface of the liquor. Whence it follows, that n a veſſel full of liquor, the ſides bear the greateſt treſs in thoſe parts next the bottom; and that the treſs upon the ſides decreaſes with the increaſe of the diſtance from the bottom, and in the ſame proportion; ſo that in veſſels of conſiderable height, he lower parts ought to be much ſtronger than he upper, to be able to withſtand the greater reſſure.

F THE ACTION OF FLUIDS ON BODIES IMMERSED IN THEM.

Archimedes, in his two books *De inſidentibus umido*, is the firſt we know of who made inquiries ncerning the ſinking and floating of bodies in uids; their relative gravities, their levities, their uations, and poſitions. He was alſo probably e firſt that ever attempted to determine in what oportion bodies differ from one another as to eir ſpecific gravities, and this he effected in order diſcover the cheat of the workmen, who had de- ſed king Hiero's crown; and though the means employed was certainly much inferior to what ould now be uſed, yet was he ſo pleaſed with his diſcovery, that not being able to contain his joy, like a madman leaping from the bath naked as he was, he is ſaid to have run about the ſtreets of Syracuſe, crying out his Ευρηκα wherever he came. Before I proceed to explain this intereſting ſubject, I muſt define ſome terms which I have only looſely explained to you.

The denſity of a body is the quantity of matter which it contains under a given bulk.

The denſity of a body is therefore meaſured by the proportion which it's quantity of matter bears to it's bulk; for the more numerous the particles of matter are in the ſame portion of ſpace, the greater is the denſity of the body, and the fewer the particles the leſs the denſity.

The ſpecific gravity of a body is the weight of it when the bulk is given; or, the ſpecific gravity of a body is it's weight compared with another body of the ſame magnitude.

It is called the *ſpecific gravity*, becauſe it is the comparative weight of different ſpecies or ſorts of bodies. Thus, if the ſpecific gravity of gold is ſaid to be to that of water as 19 to 1, the meaning is, that, bulk for bulk, or under equal dimenſions, the weight of gold is to that of water as 19 to 1; or that a cubic inch of gold will weigh 19 times as much as a cubic inch of water.

The ſpecific gravity of bodies is as their denſity, for the ſpecific gravity is the weight of a given bulk, and the weight of bodies is as their quantities of matter; therefore the ſpecific gravity of a body is as the quantity of matter contained in a given bulk, that is, as it's denſity.

The ſpecific gravity of bodies is inverſely as their bulk when their weights are equal. The ſpecific gravity of bodies is, you have already ſeen, as their denſity, and the denſity of bodies is inverſely as their bulk when the weights are equal.

Thus, if the ſpecific gravity of gold be to that of ſilver as 19 to 11, and a cylinder of gold 11 inches high weigh a pound, a cylinder of ſilver having an equal baſe and weighing a pound muſt be 19 inches high; for ſince the ſpecific gravities are 19 to 11, the bulks, that is, the heights muſt be as thoſe gravities inverted, or as 11 to 19. If the ſpecific gravity of mercury be to that of water as 14 to 1, and a cylinder of mercury of a certain weight is 30 inches high, then a cylinder of water of equal baſe muſt be 420 times as high, ſo that the height of the cylinder of water will be 14 times 30 or 420 inches, or 35 feet.

The *magnitude* of a body is expreſſed by a number denoting it's relation to ſome criterion generally uſed, and ſimilar to itſelf, as a cubical inch, foot, &c.

The *abſolute weight* of a body is relative, being expreſſed by a number denoting it's relation to ſome arbitrary or conventional ſtandard, as 1 pound, 1 ounce, of which it is a multiple or aliquot part; and in the ſame ſort of matter, ſuppoſed to be homogeneous, it depends upon and varies as the magnitude.

The ſpecific weight or gravity of the ſame ſpecies of matter, whether it's magnitude be great or ſmall, as of A, 2 A, or 3 A, is the ſame, being according to the definition of the weight of a given bulk. The object therefore of ſpecific gravities is to diſtinguiſh different ſpecies of matter from each other, in one of their moſt obvious qualities, weight of matter contained in a given ſpace.

The *weight* of any portion of matter is eaſily aſcertained, but it is not always eaſy to meaſure the ſpace occupied by a body or it's *magnitude*, and in ſome inſtances it cannot be effected without artificial methods.

It is found expedient to employ as a criterion ſome face have a greater altitude, and therefore a greater force than thoſe that are contiguous to the upper ſurface; the body muſt therefore be more violently elevated by the former than depreſſed by the other, and would therefore aſcend by the exceſs of force, were it devoid of gravity.

For when a ſolid body is immerſed in a fluid, it preſſes down, and endeavours to deſcend by the force of it's gravity, but it cannot deſcend without moving as much of the l[illegible]d out of it's place as is equal to it in bulk; [illegible] is therefore reſiſted, preſſed upwards by a force [illegible]qual *to the weight of as much of the fluid as is e[illegible]l in magnitude to the bulk of the body*, being the [illegible]ifference in weight of two columns of the fluid, whereof one reaches to the upper, the other to the under ſurface of the body.

I will endeavour to illuſtrate this by a diagram: when any hard body, as a piece of lead, is immerſed in water, the lower part of it, (m n) *fig.* 13, *pl.* 1, muſt be continually preſſed upwards juſt as much as the water itſelf in the ſame place as the lead is preſſed upwards. Now the force with which the water (m n) is preſſed upwards, is exactly equal to the force with which it would be preſſed downwards if the lead was out of the way; for every part of a fluid is preſſed as much upwards as it is downwards. The force with which (m n) would be preſſed downwards if the lead was out of the way, would be equal to the weight of the incumbent column, or of as much water as would fill the whole ſpace E H m n; therefore the force with which m n is preſſed upwards, and conſequently the force with which the piece of lead is preſſed upwards, is equal to the weight of as much water as would fill the whole ſpace E H m n, or the whole ſpace H P n o, if this ſpace be taken equal to E H m n.

Let us next conſider the force with which this piece of lead is preſſed downwards; this force is juſt equal to the weight of as much water as is above it, that is, it is equal to the weight of the column E H r s.

The difference therefore of the two preſſures will be the difference in weight between the two columns E H m n, E H t s; for the weight of the former is equal to the preſſure upwards, and the weight of the latter is equal to the preſſure downwards; conſequently the preſſure upwards will be as much greater than the preſſure downwards, as the weight of the water E H m n is greater than the weight of water E H r s.

But the difference between theſe two weights is juſt as much as would fill the ſpace r s m n, which the body fills; for juſt ſo much water added to E H r s, would make it equal E H m n: conſequently *the body is preſſed more upwards than it is downwards by a force equal to the weight of as much water as would fill the ſpace taken up by the body.* In other words, the body is acted upon by two forces in contrary directions, but the force with which the fluid acts upon it to make it aſcend exceeds the force by which it preſſes downwards; and this exceſs is equal to the weight of as much of the fluid, whatever it is, as would fill the ſpace taken up by the body.

The caſe will be the ſame whatever be the figure of the body immerſed; for ſuppoſe it to be a cone T S L V, *fig.* 15, *pl.* 1, then as every equal part of a fluid at the ſame depth is preſſed equally in all directions, if V I be equal to L V, it follows, that theſe two parts of a thin ſheet of fluid F E will be preſſed upwards by equal forces; but V I is preſſed as much upwards as downwards, therefore L V is preſſed as much upwards as V I downwards.

Now the force that preſſes V I downwards is the weight of the fluid H P V I that is above it;

part is equal in bulk to as much of the fluid as would weigh what the body weighs.

Let p t e i, *fig.* 14, *pl.* 2, be a piece of cork, then s n e i the part below the ſurface A B of the water, will be equal in bulk to as much water as would weigh what p t e i the whole cork weighs.

The force with which the water at e i is preſſed upwards, is exactly equal to the force with which it would be preſſed downwards if the cork p t e i was out of the way, becauſe every part of a fluid is preſſed equally in all directions.

But the force with which e i would be preſſed downwards if the cork was away, is equivalent to the weight of as much water as would fill the ſpace taken up by the part of the cork below the water; and conſequently the force with which e i the bottom of the cork is preſſed upwards, is equivalent to the weight of as much water as would fill up the ſpace s n e i, or the part of the cork below the ſurface.

If therefore the part which is below the ſurface has the ſame bulk as a quantity of water that would weigh what the whole cork weighs, then the preſſure upwards will be equal to the weight of the cork, and keep it from ſinking.

A body that has the ſame ſpecific gravity with the fluid into which it is immerſed, will reſt in any part of the fluid wherever it happens to be placed. For the body, you know, endeavours to deſcend by it's own weight, and is prevented from deſcending by a force equal to the weight of an equal bulk of fluid; but when the body and the fluid are of the ſame ſpecific gravity, equal maſſes of each are of the ſame weight, and conſequently the force with which the body endeavours to deſcend, and the force which oppoſes the deſcent, are equal to each other; and as they act in contrary directions, the body

ody will reſt between them, ſo as neither to ſink y it's own weight, nor to aſcend by the preſſure of the fluid upwards.

It is manifeſt from theſe poſitions, that if by ny contrivance the ſpecific gravity of a ſolid can e varied ſo as to be one while *greater*, another *leſs*, nd then *equal* to the ſpecific gravity of the fluid wherein it is immerſed, the body will ſink, or riſe, r remain ſuſpended, according to the variations of t's ſpecific gravity. And this is the caſe in the xperiment with theſe little glaſs images which I m now going to exhibit to you, which are made o aſcend or deſcend, or remain ſuſpended at pleaſure; the reaſon of which I ſhall explain to you fter you have ſeen the experiment.

The images being ſet to float on the water, the op of the veſſel muſt be covered with a bladder loſely bound about the neck of the veſſel, to the nd that the air which lies on the ſurface of the ater may not force it's way out when it is con- enſed by the hand. The images themſelves are early of the ſame ſpecific gravity with the water, ut rather a little lighter, and conſequently float ear the ſurface; the images being hollow are full f air, which, by means of ſmall holes in their heels, ommunicates with the air without. When the ir which lies beneath the bladder is preſſed by the and, it preſſes on the ſurface of the water; and as the reſſure is propagated through all the water, thoſe ortions which are contiguous to the heels of the mages are thereby forced into the holes, by which eans the air within is condenſed, and at the ſame ime the weight of the images is increaſed by the eight of the influent water; and when ſo much ater is forced in as to render the ſpecific gravity f the images greater than that of the water, the mages deſcend and fall to the bottom, where they remain as long as the preſſure above continues; but when that is taken off by the removal of the hand, the condenſed air in the images dilates and expands itſelf, and in ſo doing drives out the water, upon which account the images become ſpecifically lighter than water, and of courſe aſcend. As the preſſure on the bladder is greater or leſs, ſo muſt the quantity of water be which is forced into the images; and therefore whenever it happens, that during the aſcent or deſcent of an image, ſuch a preſſure is made as ſuffices to force in juſt as much water as is requiſite to reduce the image to the ſame ſpecific gravity with the water, the image ſtops, and remains ſuſpended; upon increaſing the preſſure it deſcends, and aſcends if it be leſſened. Some of the images begin to deſcend ſooner or riſe later than others, either becauſe they are ſpecifically heavier, or becauſe the cavity in their legs are greater in ſome images in proportion to their magnitudes, than they are in others.

This is but an experiment of mere amuſement; many and more important uſes are the reſult of our being able to determine the ſpecific gravities of bodies: to this, therefore, we ſhall now proceed.

All bodies, when immerſed in a fluid, loſe the weight of an equal bulk of that fluid; in other words, every body immerſed in a fluid loſes a part of it's gravity equal to the weight of the fluid, which would fill the ſpace taken up by the body.

A piece of lead, or of any other ſubſtance, when it is immerſed in water, is not ſo heavy as when it is out of water; for the water you know preſſes it more upwards than downwards, and the exceſs of the preſſure upwards will ſupport part of the weight. But this exceſs was ſhewn to be equivalent to the weight of as much water as has the ſame bulk with the lead, and conſequently ſince the body immerſed muſt loſe as much of it's weight as the fluid can ſupport, the lead will loſe the weight of an equal bulk of water.

Thus a cubic foot of lead r s m n, hanging by the ſtring L I, *fig.* 13, *pl.* 1, will weigh leſs in the water than it does out of it, becauſe the water by t's preſſure upward againſt the lead will ſupport a ubic foot of water, or one thouſand avoirdupois unces, for ſo much a cubic foot of water weighs, nd conſequently ſo much of it's weight the lead uſt loſe.

Again, a body endeavours to deſcend by it's hole weight; when it is immerſed in a fluid, it is upported by a force equal to the weight of the ſame ulk of that fluid; and ſince theſe two forces act n contrary directions, the weight which the body etains in the fluid will be the difference between hem, or it loſes the weight of an equal bulk of he fluid.

The following experiment, which is plain and ecifive, will render the poſition ſelf-evident; the pparatus for it conſiſts of a beam, a ſmall hollow ylindric bucket A B, and another cylinder C D, which preciſely fits the capacity of the bucket A B, *ig.* 2, *pl.* 2, (only a portion of one arm E F of the beam is repreſented in this figure). I ſuſpend the bucket by one end of the beam, at the bottom of the bucket is fixed a ſtrong thread of ſilk with a loop on the lower end; to this loop the cloſe cylinder is ſuſpended; I counterpoiſe theſe by a weight at the other end of the beam; I then ſet a jar of water under the cylinder, and gently lower the beam, and you ſee it becomes lighter and lighter upon the beam as the cylinder deſcends; now it is quite immerſed, and you ſee the equipoiſe is deſtroyed by the deſcent of the weight of the other arm. To ſhew you how much weight is loſt by the cylinder, I ſhall add the weight of a quan-

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tity of as much water as is equal in bulk to the cylinder; that is, I ſhall fill the bucket, which you know is exactly the ſame ſize; and as I do it gradually, you obſerve the equipoiſe is reſtored by degrees till the bucket is full, and then the beam is truly horizontal as at firſt, the loſs of weight being reſtored by the equal cylinder of water in th bucket.

From what has been ſaid, you now ſee clearl whence the loſs of weight proceeds; we ſee no it is no otherwiſe loſt than as it is ſuſtained by t action of a contrary force; you may therefore n ſee why the weight of a bucket of water is not pe ceived while it is in the water, not becauſe th weight is deſtroyed, but becauſe it is ſupporte not becauſe fluids do not gravitate when they a in fluids of the ſame ſort, but becauſe there is preſſure in a contrary direction which is exac equal to their gravity.

Since the weight, which a body loſes when is immerſed in a fluid, is always the weight of much of that fluid as is equal in bulk to itſelf, follows, that the weight loſt by the body canno all depend either on the depth of the fluid itſelf, the depth to which it is immerſed therein. anchor loſes no more of it's weight when it is the bottom than when it is juſt below the ſurfa for in either caſe it loſes the weight of as mu water as is equal in bulk to itſelf. It is not m eaſy to ſwim in deep than in ſhallow water, p vided the water is not ſo ſhallow as to prevent from ſtriking freely; for whatever is the dept the water, a man loſes the weight of as much w as is equal in bulk to his own body; for wh reaſon, ſhallow water will buoy him up with great force as deep water. Indeed it is eaſie ſwim in the ſea than in a river, becauſe ſalt w is ſpecifically heavier than freſh; and as a r

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loſes the weight of as much ſalt water as is equal in bulk to his body, and in the river loſes only the weight of an equal bulk of freſh water, the weight loſt here being greater, ſalt water will buoy him up with the greateſt force.

There are very few, if any animals, that are ſpecifically heavier than common water. The ſubſtances indeed of both animals and vegetables are ſpecifically heavier; the floating of either is therefore to be attributed to the cells or receptacles interſperſed within them, which are filled with air, oil, &c. ſubſtances lighter than water; ſo that, taken together, they form a maſs ſpecifically lighter than a comparative bulk of common water.

Further, the bulk of the body is increaſed by diſtending the cheſt in inſpiration; this has been tried by an experiment on a fat man of an ordinary ſize, by finding what weight he could ſupport ſo as to have the top of the head juſt above water. When his breaſt was full of air; he was found to riſe with fourteen pounds of lead without ſtriking out in the leaſt, and two ounces more would have kept him under; but when his breaſt was not thus diſtended, he could only bring up eleven pounds.

All equal ſolids, though of different ſpecific gravity, when they are immerſed into the ſame fluid, loſe an equal weight. The weight which gold, or ſilver, or lead, or ſtones, or any other body loſes in water, does not at all depend upon the ſort or figure of a body, but upon it's bulk or ſize. The ſtone loſes the weight of an equal bulk of water, ſo does the lead; when, therefore, they are of the ſame ſize, they each of them loſe the weight of the ſame quantity of water, that is, they loſe an equal weight: but if two bodies of the ſame ſort differ in ſize, they will loſe different weights in proportion to their ſize.

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To prove that the loſs of weight is not affected by the abſolute weight of the body, but depends on it's ſize, alter the weight of the cylinder, by adding to or diminiſhing the number of ſhot contained in it, and then repeat the experiment with it and the bucket as before, and you will find the event the ſame.

In the ſame manner ı ſhew that all bodies, however different their ſ fic gravity may be, if their magnitudes be equ ſuffer an equal loſs of weight in the ſame fluid; u s a cylinder of block-tin, equal in dimenſions to ıe braſs cylinder, but ſpecifically lighter, being i merſed in water, will loſe the ſame weight.

Bodies of the ſame weight, but of different ſpecific gravities, loſe unequal parts of their weights when they are immerſed in the ſame fluid. Thus, this piece of gold in one ſcale weighs juſt as much as a piece of copper in the other ſcale, when they are weighed in air. Now hang them by horſe-hairs on the hooks of your ballance, and let them down into the glaſs veſſels, and as ſoon as they are immerſed in the water, the equilibrium will be deſtroyed, and the gold will outweigh the copper; for as they have equal weights, their bulks are as their ſpecific gravities, that is, the gold will be as much leſs than the copper as the ſpecific gravity of the gold is greater than that of copper; the gold, therefore, becauſe it is the ſmaller of the two bodies, will loſe leſs of it's weight than the copper does, and will conſequently outweigh the copper.

If the gold and the copper are made of the ſame weight, when they are under water, then by drawing them out of the water the copper will become the heavier; for when they were under the water, each of them loſt as much of th weight as the water could ſuſtain, that is, each bulk for bulk heavier than the fluid, by being immerſed it loſes only the weight of an equal bulk of the fluid, and conſequently the *reſidual* or remaining gravity of the ſolid muſt carry it down to the bottom, or make it *ſink*.

On the other hand, if the ſolid has leſs weight in the ſame bulk than the fluid, then it cannot by it's weight diſplace or raiſe upwards it's whole bulk of the fluid, but only ſo much of it as is equal to it's own weight, and from this deficiency in weight it will be only partly immerſed, and will therefore *ſwim* upon the upper part of the fluid.

Of all the animals, however, thrown into the water, man is the moſt helpleſs; the brute creation receive the art of ſwimming from nature, while man can only acquire it by practice; the one eſcapes without danger, the other ſinks to the bottom. Some have aſſerted, that this ariſes from the different ſenſibilities each have of the danger; the brute unterrified at his ſituation, ſtruggles, while his very fears ſink the lord of the creation.

But much better reaſons may be aſſigned for this impotence of man in water, when compared to other animals; and one is, that he has actually more ſpecific gravity, or contains more matter within the ſame ſurface than any other animal. The trunk of the body in other animals is large, and their extremities proportionably ſmall; in man it is the reverſe, his extremities are very large in proportion to his trunk. The ſpecific weight of the extremities is proportionably greater than that of the trunk in all animals, and therefore man muſt have the greateſt weight in water, ſince his extremities are the largeſt.

Beſides this, other animals to ſwim have only to walk (as it were) forwards upon the water;

the motion they give their limbs in ſwimming is exactly the ſame they uſe upon land; but it is different with man, who makes uſe of thoſe limbs to help him forwards upon water, which he employs to a very different purpoſe upon land.

LECTURE XXXIV.

ON THE METHODS OF ESTIMATING THE SPECIFIC GRAVITY OF BODIES, ON AIR-BALLOONS, &c.

FROM the principles explained to you in the preceding Lecture, it will be eaſy to ſhew you in what manner you may eſtimate the ſpecific gravities of different bodies, whether ſolid or fluid. Now the ſpecific gravity of a body is the weight of that body, under a known and determinate magnitude; as a cubic inch, a foot, &c. To acquire this knowledge, the body is to be weighed *hydroſtatically*; that is, 1. in air; 2. in water. You know that a body immerſed in water diſplaces a volume of water exactly equal to it's own, and that it loſes a portion of it's weight exactly equal to the volume diſplaced; we therefore obtain by this mode, 1. the weight of the body; 2. the weight of a volume of water perfectly equal in bulk to that of the body. Theſe two weights, compared together, give the relation between the ſpecific gravity of water, which we ſuppoſe to be known, and that of the given body, by making the following proportion, in which 1000* repreſents the ſpecific gravity of water. The weight of the volume of water diſplaced by the body, is to the weight of this body, as 1000 is to a fourth term repreſenting the ſpecific gravity of this body:

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* In hydroſtatic calculation, water, as the ſtandard from which all the reſpective gravities are taken, is reckoned as unity, or 1, 10, 100, 1000, &c. as the caſe requires.

for the ſpecific gravities are as the weights of equal bulks; therefore the ſpecific gravity of the fluid is to that of the body, as the weight loſt in the fluid is to the whole weight.

Now let us ſuppoſe a piece of gold to weigh 38 grains in air, and only 36 grains when weighed in water; it has therefore loſt two grains. Reaſoning, therefore, from what has been already proved, we ſay the gold has loſt the weight of as much water as is equal in bulk to itſelf. But the gold itſelf weighs 38 grains; conſequently, bulk for bulk, the weight of water is to that of gold, or the ſpecific gravity of the fluid to that of the ſolid, as 2 to 38; that is, as the weight of the fluid is to the whole weight.

Thus the whole art of comparing the ſpecific gravity of bodies, conſiſts in finding out what the body weighs in air, and how much of that weight is loſt in water; and then dividing the firſt weight by the difference between the firſt and ſecond weight, and the quotient of this diviſion ſhews how many times the body is heavier than water.

The definition of *ſpecific gravity* implies compariſon. Some kind of body muſt be fixed upon, whoſe gravity muſt be made a ſtandard for the gravity of other bodies of equal bulk to be compared with. This ſtandard body ſhould have two properties; firſt, it muſt be eaſy to be had, or come at, upon all occaſions; and, ſecondly, it ſhould be of as fixed and unalterable a nature as poſſible, that there may be no variation in it's gravity in equal bulks, in different times or places.

Now as the beſt way of diſcovering the ſpecific gravities of bodies is by immerſion, the body muſt be of the fluid kind; and, among fluids, *water* is that which poſſeſſes in the higheſt degree the requiſites for a ſtandard. Diſtilled water is the leaſt objectionable, next to this pure rain-water; but common water, for many purpoſes, will anſwer exceeding well.

The ſpecific gravity, or weight, of a given bulk of diſtilled water is nearly at all times the ſame; and by comparing this with other ſubſtances, the ratio of their ſpecific gravities may be diſcovered; and denoting the ſpecific gravity of water, by any number, taken at pleaſure, the numbers expreſſing the ſpecific gravities of other bodies are hence given.

As the weight of one cubical foot of pure diſtilled water is equal to 1000 ounces avoirdupois, if it's ſpecific gravity be denoted by 1, or 1000, the weight of one cubic foot, or other meaſure, of other ſubſtances, is hence found, and tables of the ſpecific gravities of bodies are formed.

One ounce avoirdupois is equal to 437.5 grains, and an ounce troy to 480 grains; conſequently, one avoirdupois pound is to one troy pound, as 437×16 to 480 × 12, or as 1750 to 1440.

A cubic foot of water is equal to 1000 ounces avoirdupois, or 62.5 lb. avoirdupois; whence we find it to be equal 75.95 lb. troy.

A cubic inch of water is equal 253.18 grains, or .57869 parts of an avoirdupois ounce; and 253.18 grains, or 5274 parts of one troy ounce.

THE USE OF THE HYDROSTATIC BALLANCE, IN DETERMINING THE QUALITY OF GOLD, &c.

Being able to determine the ſpecific gravities of bodies, you will thence be able, by weighing metals in water, to diſcover their adulterations or mixtures, with greater exactneſs than by any other method whatſoever. By this means the counterfeit coin, which may be offered you as gold, will be eaſily diſtinguiſhed, and known to be a baſer

: principal and diſtinguiſhing qualities of ld, are the ſimplicity, minuteneſs, and cloſe hesion of it's parts; whereby a greater number hoſe parts is contained in leſs ſpace than any body with which we are acquainted.

As all bodies weigh in proportion to their quantity of gravitating matter, under the ſame bulk, the ſpecific weight of gold muſt be ſuperior to that of other metals.

It follows from hence, that if gold be adulterated with any other metal, it's *ſpecific* gravity, or comparative weight, muſt be *leſs* in proportion to the quantity of *alloy*. The *weight*, therefore, of gold, is a ſure criterion of it's quality.

In order to determine the preciſe quantity of alloy compounded with gold, gold muſt be weighed with ſome other maſs as a *ſtandard*, and their relative gravities be computed. I have already ſhewn you, that water is the moſt convenient ſtandard.

It will therefore, from what has been ſaid, be eaſy to you, by means of an accurate hydroſtatic ballance, to determine it's quality and real value. Weigh a piece of gold firſt in air, weigh it then in water, ſubtract it's weight in water from the weight in air, and the difference ſhews the *loſs* it has ſuſtained by being weighed in a denſer medium. Divide the *weight in air* by the *loſs in water;* the quotient ſhews the ſpecific gravity, or how many times gold is heavier than water.

On the contrary, the ſpecific gravity of *ſterling gold* being known, if the *weight in air* of any piece of gold coin be divided by the *ſpecific gravity* of ſterling gold, the quotient ſhews what ought to be it's *loſs* in water; and if it be found to loſe more, the gold is bad, or has too great a quantity of alloy.

Gold is about eighteen times as heavy as common water; the ſpecific gravity of ſterling gold being to the weight of water as 17.793 to 1. If, therefore, a guinea weighs in air 129 grains, when weighed in water it muſt loſe 7.25, or 7½ grains of it's weight; becauſe as 7.250 is to 129, ſo is 1 to 17.793; ſo that a quantity of water equal in bulk to a ſterling guinea, weighs 7¼ grains. I ſhall ſhew you hereafter how to compute the proportion in which the quantity of alloy in counterfeit gold exceeds that which is allowed to a ſtandard, and proceed to deſcribe the hydroſtatic ballance, and the method of applying it to uſe.*

OF THE HYDROSTATIC BALLANCE.

The beams of theſe ballances are in general made from eight to ten inches long; and with the perfections neceſſary to a good ballance-beam, as pointed out in my Lecture on Mechanics, it either reſts upon a ſtand or fulcrum, as at *fig.* 3, *pl*, 2, or is pendent, as at *fig.* 4, *pl.* 2.

To this beam are adjuſted a pair of ſcale-pans, which may be taken off at pleaſure. There is alſo another ſmaller pan, of equal weight with one of the others, furniſhed with ſhorter ſtrings, ſo as to admit a veſſel of water to be placed under it. When the ballance is uſed for hydroſtatic purpoſes, this pan is to be ſuſpended at one end of the beam, and one of the common ſcale-pans at the other.

The glaſs *bucket* is to hold any ſolid body to be weighed in water, and is to be ſuſpended by the horſe-hair to the hook at the bottom of the ſmall ſcale. There is a weight to be placed in the oppoſite le, in order to ballance the bucket exactly

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* See an excellent little tract on the uſe of the hydroſtatic ballance, by Becket.

braſs *tongs* are for the ſame purpoſe, and uch ſubſtances as cannot conveniently be the bucket.

ſmall braſs *nipper* is intended for weigh- ld coin; which may be more accurately by this than in the *bucket*, which is prin- deſigned for ſuch things as cannot well be in the nipper or gs: the beam will turn much eaſier with e r theſe, than with the other. A ſcale-bea led at each end with a conſiderable weight, is nſible of the addition of a ſmall one: beſides, iſting medium of water, through which the w rface of the bucket and it's contents muſt paſs, ens the vibration of the beam, and renders the ope ration both tedious and uncertain.

The glaſs ſolid is made uſe of to determine the ſpecific gravity of fluids.

Each of theſe appendages has, you ſee, a reſpective weight, for a *ballance in water*, which are diſtinguiſhed by different marks. Theſe weights are intended to ballance them *exactly*; but their correctneſs may be injured by different circumſtances, for water varies conſiderably in it's denſity, according to the temperature of the air; in hot weather it is lighter, in cold it is heavier: in the former caſe the ballance may appear rather too light, and in very cold weather rather too heavy. Whenever this happens, you muſt reſtore the equilibrium by a ſmall weight, dropped into the ſcale that requires it, before any hydroſtatic experiments can be performed with accuracy. From hence it is natural to conclude, that the ſpecific gravity of the ſame ſubſtances will be different at different times: this variation is, however, ſo ſmall, particularly in the weight of gold, as not to be regarded in common experiments.

For eaſier computation, I ſhall uſe tenths of grains for the ſubdiviſions in theſe experiments.

TO FIND THE SPECIFIC GRAVITY OF SOLIDS.

Weigh the ſubſtances firſt accurately in air, ſetting down with a pen the weight in grains and decimal parts; then hang on the ſmall water-ſcale to one end of the beam; place under it the glaſs veſſel, pouring water in till it be filled to within three quarters of an inch from the brim: let the body to be weighed be then placed in the nippers, tongs, or bucket, as is moſt convenient; and, immerging it in the water, let it be ſuſpended by the horſe-hair to the hook at the bottom of the water-ſcale.

Take care that the ſame weights that ballanced the body in air be in the oppoſite ſcale, and likewiſe the proper *ballance water-weights*, and that no air-bubble adhere to any part of the ſubſtance in the water, which will render it apparently lighter.

The *oppoſite* ſcale to that which contains the ſubſtance will now greatly preponderate; weights ſhould therefore be put into the water-ſcale till the equilibrium be reſtored.

The pen and ink will now finiſh the operation. Divide the *weight in air* by the *loſs in water*; that is, divide the number of grains in the large ſcale, by thoſe in the ſmall one, and the quotient will ſhew the ſpecific gravity, or how many times heavier the ſubſtance that was weighed is than water.

If the weight in the ſmall ſcale be *ſubtracted* from that in the other, it will ſhew the *reſpective*

gravity

gravity of the weighed ſubſtance, or the weight wit[illegible]ch it will be evenly ballanced in water.

[illegible] will be rendered plainer by an example or tw[illegible] Weigh this new guinea in air; you have found [illegible]s weight to be 129 grains. Now fix it in the nippers, ſuſpend them from the water-ſcale, and immerge it in the water [illegible] the ballance-weight of the nippers being in t[illegible]ppoſite ſcale), it appears to be lighter; but [illegible] grains into the water-ſcale, and the equili[illegible] will be reſtored, which ſhews that the guinea is [illegible]od, or that ſterling gold is 17.793 times as heavy a[illegible] water.*

Example 2. Here is a guinea that I ſuſpect to be bad, or counterfeit [illegible]ld, though upon weighing it in air it is found to be of full weight, or 129 grains. Now let us weigh it in water: it has loſt 8.12 grains; what is it's ſpecific gravity?

As the loſs in water is to the weight in air, ſo is 1 *to ſpecific gravity*; therefore as 8.12 to 129, ſo is 1 to 15.886; for 129.00, divided by 8.12, gives 15.886 for the ſpecific gravity, ſhewing that the gold is much worſe than ſterling.

Example 3. If a piece of ſilver weighs 636 grains in air, what is it's ſpecific gravity, ſuppoſing it to loſe 60.7 when weighed in water? 60.7 : 636 : : 1 : 10.478 the ſpecific gravity; by which it appears to be good ſilver.

Example 4. How much heavier than water is flint-glaſs? A piece of white flint-glaſs weighed 169.05, and loſt 50.60.

50.60 : 169.05 : : 1 : 3.341

ſo that it was ſomewhat more than 3⅓ times heavier than it's bulk of water.

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* This is nearly the weight of a new guinea, but not ſtrictly ſo: it's real weight (valuing gold at £3 17 10½ per ounce) is 129.438, or nearly 5 dwts. 9½ grains: the loſs in water w therefore be 7.27.

Example 5. Mercury, though properly a fluid,
be weighed as a ſolid. Thus, put 1 ounce, or
grains of mercury into the glaſs bucket, and
hing it in water, it will be found to loſe nearly
t 351 grains. Mercury therefore is heavier
water as 13.67 to 1.

The method is the ſame for moſt other ſolid
ances that are ſpecifically *heavier* than water;
hoſe that are *lighter*, the proceſs is ſomewhat
rent.

When any thing floats on the ſurface of a fluid,
ſplaces juſt ſo much of the fluid as is equal in
ht to the weight of the whole floating body.
oſe a hollow cube of tin, 2 inches ſquare, to
h 1 ounce; this being floated on water, may
ppoſed to ſink in it half an inch, or one-fourth
of the whole: if ſo, a body of water 2 inches
re, and half an inch thick, muſt weigh 1 ounce,
l to the weight of the cube, which would be 4
s ſpecifically lighter than water. The cube
ld require an additional weight of three ounces
nmerge it totally in the fluid; the *reſpective*
ity of the water to the cube is therefore as 3 to
nd conſequently a bulk of water equal to the
would weigh 4 ounces.

From hence the method of weighing light ſub-
es ſpecifically, is as eaſily conceived and put
ractice as that of weighing the heavier ones.
ugh ſeveral different appendages have been
e to the hydroſtatic ballance for this purpoſe,
appear in general to be unneceſſary, as moſt
ances that are not too large to go into the
tongs, may very accurately be weighed in it.

Example 6. Suppoſe it was required to find
ſpecific gravity of a piece of dry *beech-wood*,
hing 59.50 grains.

Having ſet down the weight of the wood in
fix it in the tongs, and ſuſpend the whole to

the water-ſcale, placing the ballance-weight
tongs in the oppoſite ſcale. In the foregoi
periments, we let the weights with which th
ſtance was weighed *remain in the ſcale*; we a
to *take out* all of them, except the *ballance-w*
and, upon immerging the tongs and wood i
water, they will appear to be *lighter* than the
alone. That adding a weight to one end of a
beam ſhould make the other end prepon
ſeems to be as *paradoxical* as the *weighing of*
but it ceaſes to be ſo when we conſider t
bodies aſcend by means of their *levity*, but by
of the greater denſity of the medium in whi
are immerſed. The wood pulls the tongs
with a force equal to the *reſpective gravity*
water; ſo that it requires as much weight to
the equilibrium, as the wood is lighter t
bulk of water. Small weights are therefor
put into the water-ſcale, till the ballance b
and *the weight of the wood in air*, added t
ſmall weights, will be *equal to the weight o*
of water of the ſame ſize as the wood; conſe
the *ſpecific gravity* will be *as the weight of*
bulk of water is to the *weight of the wood in*

When I weighed the wood, I put 16.7
into the water-ſcale, before the ballance
even. 16.70 added to 59.50 (the weight
wood) make 76.20; therefore

76.20 : 59.50 : : 1.000 : .781 the ſpeci
vity of the beech.

Example 7. A piece of very dry *cork*,
ing in air 24.3 grains, required 149.2 to be
the water-ſcale, to reſtore the ballance.
added to 24.3 make 173.5 (the weight of a
water equal to the cork.) As 173.5 : 24.3 : :
.152 the ſpecific gravity of the cork;—
lighter than water.

The ſpecific gravity of another piece of cork was .241, or about 4 times lighter than water.

N. B. In weighing of thoſe bodies whoſe pores readily imbibe the water, the quicker the experiment is performed, the more likely it is to be correct.

METHOD OF FINDING THE SPECIFIC GRAVITY OF FLUIDS.

That which is meant by the term *ſpecific gravity* of bodies, being nothing more than the difference, or comparative weight of thoſe bodies to that of common water, we might eaſily find the ſpecific gravity of any kind of *fluid*, by weighing a quantity of it againſt an equal quantity of water; but as a ſolid body, when immerſed in a fluid, loſes as much of it's weight as a bulk of the fluid equal to the body weighs, a more convenient and accurate method is the immerſion of a *ſolid*, of ſome determinate weight, in the fluid whoſe ſpecific gravity we deſire to know.

For this purpoſe is the conical piece of *ſolid glaſs*, belonging to the hydroſtatic ballance; whoſe weight, both in air and in water, being known, ſhews immediately the weight of the fluid into which it is ſuſpended; the ſolid being borne up by the fluid in a proportion equal to it's reſpective gravity.

Suppoſe the glaſs ſolid to weigh in air 1464 grains, and that, when it is ſuſpended from the water-ſcale, and immerged in water, it loſes of it's weight 445 grains; this would be the weight of a bulk of water equal to the ſolid. The ballance-weight for the ſolid muſt be made juſt equal to what it weighs in water, i. e. 1019 grains.

Whatever fluid is to be weighed, let it be put into the glaſs recipient; ſuſpend the ſolid to the

hook

hook of the water-ſcale, and let it hang freely in the liquor, putting the ballance-weight in the oppoſite ſcale. If the fluid be heavier than water, the ſolid will riſe in it; if lighter, it will ſink to the bottom of the recipient. In either caſe ſmall weights are to be put into the lighter ſcale, till the ballance be made even.

1. When the fluid is *lighter* than water, the weight *gained* by the glaſs ſolid is to be *ſubtracted* from the weight of a bulk of water equal to the ſolid [445], and the remainder is the weight of an equal bulk of the fluid, or it's ſpecific gravity to water.

Example 1. When ſuch a glaſs ſolid as the above was immerſed in *brandy*, it ballanced 38.2 grains more than in water. This, taken from 445.0, leaves 406.8; therefore the ſpecific weight of the brandy was to water as 406.8 to 445.

To reduce it to it's proper terms, multiply the difference [38.2] by 1000, (the denominator of water) and divide the product by 445. As 445 : 38.2 : : 1000 : 86; ſubtract 86 from 1000, there remain .914, the ſpecific gravity of the brandy.

From hence it appears, that the brandy weighed 86 parts in 1000, or about $\frac{1}{12}$ leſs than water.

Example 2. In *rum* the ſolid ballanced 40.3 grains more than in water; as 445 : 40.3 :: 1000 : 91 —91 from 1000, remain .909. The ſpecific gravity of the rum to water was therefore .909, or about $\frac{1}{11}$.

Example 3. When the ſolid was immerſed in highly rectified *ſpirit of wine*, it ballanced 73.6 more than in water; therefore 445 : 73.6 :: 1000 : 165 —165 from 1000, remain .835, or $\frac{1}{6}$.

It appears from theſe examples, that the *hy-*

droſtatic ballance is a certain and correct inſtrument for determining the *ſtrength of ſpirits*, perhaps more ſo than the moſt accurate *hydrometer* that has yet been made for that purpoſe.

It is of conſiderable conſequence to diſtillers, and dealers in ſpirituous liquors, to know the preciſe point of ſtrength which is termed *proof:* though this, indeed, is rather arbitrary, than any fixed ſtandard; but the degree of ſtrength which, I am informed, is now called merchantable *proof*, fixeth the ſpecific gravity of the ſpirit to water at .930.

930 taken from 1000 leaves 70; therefore 1000 : 70 : : 445 : 31.15. So that in *proof ſpirit*, a glaſs ſolid of the weight above-mentioned, muſt ballance 31.15, or about 31¼ grains more than in water.

It may eaſily be found in what proportion the ſpirit is *above* or *below* proof, by obſerving what quantity of *water* or *alcohol* is neceſſary to be mixed with it, in order to bring it to the above ſtandard; and it might be immediately known, by comparing the weight of the ſpirit with that of water, if the ſpecific gravity of both, when compounded, remained in the ſame ratio as when ſeparate; but as it is found that, when water is mixed with ſpirit, the ſpecific gravity of the compound is *greater* than that of the water and the ſpirit before they are compounded, the calculation muſt therefore turn out incorrect. For inſtance,

A quantity of the *rum*, before-mentioned, equal in bulk to the glaſs ſolid, weighed very nearly 405 grains, an equal bulk of water 445 grains; ſuppoſe, then, that in order to reduce the rum to *proof*, one *fifth part* of water was to be mixed with it;

Water - 1 = 445
Rum - 4 = 1620

5) 2065

Mean weight = 413

By this it appears, that a quantity of the compound, equal in bulk to the glaſs ſolid, ſhould weigh 413 grains, an[illegible]ſequently that the ſolid, when immerſed in it, ſhould ballance 32 grains more than in water; in which caſe it would ſtill be ſomewhat above proof.

But, upon trial, it will be found to ballance not much more than 29½, and that there muſt be but little more than *one-ſeventh* part of water mixed with the rum to reduce it to the given ſtandard.

Immediately after water is mixed with ſpirit, the compound appears *lighter;* but in a few hours afterwards, when the particles of each are more intimately united, it's bulk diminiſhes, and conſequently the ſpecific gravity increaſes.

From a few experiments of this kind, the theory will appear ſufficiently plain; and a table might eaſily be formed for ſhewing by inſpection what quantity of water is neceſſary to be put to any given quantity of ſpirit, to render it true proof.

2. When fluids are ſpecifically *heavier* than water, the glaſs ſolid, as before obſerved, will *riſe* in ſuch fluid (the water ballance-weight being in the oppoſite ſcale) and appear to be lighter; ſmall weights are therefore to be put in the water-ſcale, till the equilibrium be reſtored; and the *loſs* which the ſolid ſuſtains, by being weighed in the heavy fluid, is to be *added* to the weight of a bulk of water equal to the ſolid; the ſum ſhews the ſpecific gravity of the fluid to water.

Example 4. Suppoſe it was required to find the ſpecific gravity of *ſea-water*, or how much heavier it is than rain-water.

Let the ſolid be ſuſpended, as uſual, to the water-ſcale, and immerſed in the ſea-water, putting the ballance-weight in the oppoſite ſcale. It will require 11.6 grains to bring it to an even ballance.

As 445 : 11.6 : : 1000 : 26.

The ſpecific gravity is therefore 1026; which ſhews that ſea-water is 26 parts in 1000, or $\frac{1}{38}$ heavier than rain-water; or that there muſt be 1026 meaſures of rain-water, to weigh as much as 1000 meaſures of ſea-water. The method is the ſame for every other fluid ſpecifically heavier than water.

The ſpecific gravity of *ſalt* and *water*, in equal quantities (in meaſure) is 1205; or about one-fifth heavier than common water.

METHOD OF DISCOVERING THE PROPORTION OF ALLOY MIXED WITH GOLD.

The ſpecific gravity of *ſterling* or *money* gold, as before obſerved, is 17.79, which is the ſtandard made uſe of in the following calculations, as it comes the neareſt to the average weight of the current Britiſh coin. The ſpecific gravity of pure, or very fine gold, is indeed conſiderably more; in ſome tables it is made 19.64, but it is ſeldom met with ſo heavy as this. The ſpecific gravity of good *ſilver* is 10.37; of *copper* 8.83.

If, then, a maſs be compounded of *gold* and *ſilver*, the ſpecific gravity of the compound may be thus found, without the uſe of the ballance.

Example 1. Suppoſe a maſs of metal, half *gold* and half *ſilver* [in weight], to weigh in air 258.8 grains, each metal in the compound maſs, firſt, find it's ſpecific gravity, and then ſubtract the ſpecific gravity of the *inferior* metal from that of the *compound*, and the remainder ſhews the ratio of *gold*; then, if the ſpecific gravity of the *compound* be ſubtracted from that of the *gold*, the remainder is the ratio of the *inferior* metal.

It muſt be obſerved that, in the preceding examples, the quality of the alloy, with which the gold is compounded, i[illegible]oſed to be *known*, together with it's ſpecifi[illegible]vity; but this is ſeldom the caſe; it is not often diſcoverable with what particular metal or metals a counterfeit guinea is adulterated, much leſs their exact *ſpecific gravity*, which is neceſſary to be known: the foregoing experiments, then, may appear to be calculated more for amuſement, than for any real utility, in determining the value of bad gold. This concluſion, however, would be rather too precipitate; ſuch experiments and calculations have not only a tendency to familiarize the ſubject, but they lead directly to the deſired point.

Gold may be made to retain a very ſpecious appearance, and yet be rendered much worſe than *ſterling*, by being adulterated with inferior metals, —*ſilver*, *copper*, ſome kinds of *braſs*, &c. and though the weight of theſe, after the maſs is compounded, cannot be preciſely aſcertained, nor conſequently the exact ratio of the gold; yet, by taking the *mean* ſpecific gravity of the metals generally uſed for adulterating of gold, and attending to the weight, colour, &c. of the compound, a pretty correct judgment might be formed of the nature of the *alloy*; and if this be *nearly* true, the hydroſtatic examination cannot be very erroneous, but will generally prove ſufficiently accurate.

As a ſterling *guinea*, when weighed in water, is found to loſe 7¼ grains of it's weight, if it loſes more than this, the uſual method has been to reckon the gold ſo much worſe than ſterling, by allowing or deducting from it's value a certain ſum for every grain that it loſes more than 7¼; and perhaps, a more correct method cannot be taken, if that ſum be adequate to the weight of the alloy.

A piece of good *ſilver*, of equal weight with a *guinea*, (or 1.294 grains) when weighed in water, loſes of it's weight 12.47 grains, which is 5.2 more than the guinea loſes:

pence. *pence.*
5.2 : 252 :: 1 : 48.4

If therefore a *guinea*, or other piece of gold coin, be adulterated with *ſilver*, *four ſhillings*, at leaſt, muſt be deducted from it's value, for every grain that it loſes more than it would loſe were it ſterling gold.

A piece of *copper*, of equal weight with a guinea, loſes in water 14.65, which is 7.38 more than a guinea.

pence. *pence.*
7.38 : 252 :: 1 : 34

So that, if ſterling gold be adulterated with *copper*, *two ſhillings and ten-pence* is to be deducted from it's value for every deficient grain; and the ſame method will aſcertain the proportion for every other ſpecies of alloy.

Counterfeit guineas are ſeldom found to be adulterated with *ſilver* alone, but more generally with *copper*, with a ſmall quantity of ſilver; or with metals whoſe weight is nearly equal to that of copper.

From the mean weight of theſe metals compared with different *aſſays* that have been made of counterfeit gold, it appears, that if three ſhillings be allowed for every grain deficient in the ſpecific gravity, it will come very near the truth, and may be generally relied on as ſufficiently correct.

OF THE MEASURING THE SPECIFIC GRAVITY OF BODIES BY THE HYDROMETER.

If there are ſeveral fluids to be compared, and a given body which is [illegible]cally lighter than any of them is made to float [illegible] their ſurface, the parts of the body that ſink below the ſurface in theſe different fluids will be inverſely as their ſpecific gravities.

A piece of cork will ſink deeper in ſpirits of wine than in water; and the part of it which ſinks below the ſurface of the ſpirits will be to the part which ſinks below the ſurface of the water as the ſpecific gravity of the ſpirits is to that of the water when they are inverted, that is, as the ſpecific gravity of the water is to that of the ſpirits. The part which ſinks below the ſurface in the ſpirits, is the bulk of as much ſpirits as is equal in weight to the whole cork; and the part which ſinks below the ſurface of the water, is the bulk of as much water as is equal in weight to the ſame cork. Theſe parts are therefore to each other as the bulks of equal weights of ſpirits and water; but theſe bulks, and conſequently the parts of the cork that ſink below the ſurface, are inverſely as the ſpecific gravities of ſpirits and water.

Hence we can diſcover the ſpecific gravity of different ſolids, by plunging them in the ſame fluid; ſo we can diſcover the ſpecific gravity of different fluids, by plunging the ſame ſolid body into them; for in proportion as the fluid is light, ſo much will it diminiſh the weight of the body weighed in it. Thus, we know, that ſpirit of wine has leſs ſpecific gravity than water, becauſe a ſolid

than

that will ſwim in water, will ſink in ſpirits of wine. The ſtronger any fluid is, the greater will be it's reſiſtance to any ſolid immerſed; ſpirit of nitre has greater ſpecific gravity than water; a ſolid that will ſink in water, will ſwim in ſpirit of wine.

The method of comparing fluids with each other by means of the hydrometer or aerometer, depends on this principle. Before I enter into a minute explanation of the hydrometer and it's uſes, I ſhall ſhew you one or two pleaſing experiments with fluids of different weights. Here is a glaſs veſſel which is divided into two parts, communicating with each other by a ſmall opening: fill the lower part with red wine, and then pour water gently into the upper part. As the red wine is lighter than water, you will ſoon ſee it riſing like a ſmall thread up through the water, and diffuſing itſelf upon the ſurface; it has continued doing ſo till the wine and water have changed their places, the water is in the lower half, and the wine in the upper half of the veſſel.

Here is a ſmall bottle, whoſe neck is long and not more than the one-ſixth of an inch in width; I fill the bottle with red wine, and then place it in this glaſs veſſel full of water, &c. which is between two or three inches higher than the bottle; the wine, you ſee, begins to come out of the bottle, and riſes in the form of a ſmall column to the ſurface of the water, while the water enters the bottle and ſupplies the place of the wine; the weight of the water carries it down, and forces up the wine. You may alter this experiment by filling the bottle with water and the veſſel with wine, and then placing the bottle inverted in the veſſel; the water will deſcend to the bottom of the veſſel, and the wine will mount up into the bottle.

The hydrometer (*fig.* 19, *pl.* 2,) is one of the moſt uſeful philoſophical inſtruments; for though the hydroſtatic ballance be the moſt general inſtrument for finding the ſpecific gravities of all ſorts of ſubſtances, yet the hydrometer is better to diſcover with eaſe and expedition thoſe of fluids. It conſiſts of four parts, 1. A ball of metal, ivory, or glaſs. 2. A tail and weight to poiſe the inſtrument, that a certain part of the inſtrument may be always downmoſt in the liquor. 3. A long ſtem ariſing from the oppoſite and upper part of the inſtrument. 4. A ſhoulder on the upper part of this inſtrument, for occaſionally placing of weights to cauſe the inſtrument to ſink ſo far that the ſurface of the fluid may always cut the ſtem at a particular point.

When this inſtrument is ſwimming in the fluid, the part of the fluid diſplaced by it, will be equal in bulk to the part of the inſtrument under water, and equal in weight to the whole inſtrument.

Suppoſe the weight of the whole to be 4000 grains, and it is evident you can by this inſtrument compare together the different bulks of 4000 grains of various fluids: for inſtance, if the weight at bottom be ſuch as ſhall cauſe the hydrometer to ſink in rain water till it's ſurface came to the middle point of the ſtem; and if after this it be immerſed in common ſpring water, and the ſurface thereof is one-tenth of an inch below the middle point, it is evident, that the ſame weight of each water differs in bulk only by the magnitude of one tenth of an inch in the ſtem.

Now, ſuppoſe, for eaſe in calculation, the ſtem were ten inches long, and weighed 100 grains, then every tenth of an inch would be one grain weight; and ſince the ſtem is of braſs, and braſs is about eight times heavier than water, the ſame bulk of water will be equal to one-eighth of a grain, and conſequently to one-eighth of $\frac{1}{4000}$ part of the whole, that is, a 320,000 part of the whole bulk.

A variety of hydrometers have been conſtructed of late for the purpoſe of aſcertaining the ſtrength of ſpirits; but as government, to avoid diſputes, have been under the neceſſity of paſſing an act to conſtitute *Clarke*'s hydrometer (for a ſhort time) the only legal one, it will be unneceſſary to deſcribe to you the various conſtructions that have been made, as they are by this means rendered of little uſe; and as the ſubject has been taken up by men of the firſt abilities, no doubt ſome inſtrument will be contrived that will anſwer the purpoſes of government for regulating the revenue, and at the ſame time to accommodate the public. Mr. Ramſden, in an excellent paper on this ſubject, has ſhewn, that to anſwer theſe valuable purpoſes, four ſubjects muſt be well aſcertained.

1. A method of proportioning and expreſſing n meaſures the quantities of ſpirits in compounds, nd of determining their ſpecific gravities.

2. A means of aſcertaining the increaſe or iminution in the bulk of a given compound ariſng from different degrees of temperature.

3. The application of the experiments under he two preceding heads to the conſtruction of an ydrometer, which ſhall give the ſpecific gravity of y compound in thouſandth parts of that of diſlled water; and at the ſame time the quantity of irits of a given ſtrength in the compound in undredth parts of the volume.

4. A method to determine the proportion of irits to water in the compound, now called *proof*, hich the commiſſioners of the cuſtoms have ſtated weigh ſeven pounds twelve ounces per gallon, the temperature of 55 degrees; for which pur-

poſe it is neceſſary to have an exact gallon meaſure.*

From hence you may ſee that the determining the ſpecific gravities of fluids, in order thereby to obtain the ſtrength of ſpirituous liquors, is a very complicated problem. Mr. De Luc has ſhewn, that when an hydrometer is employed, there are three phyſical effects, the degrees of which are not proportionate to their apparent cauſes, and which are united in one effect, namely, the different ſinking of the hydrometer.

1. It will not always ſink in liquors of different denſities proportionally to theſe denſities, on account of the changes of it's own bulk by heat, and the poſſible irregularities of it's branch. 2. It will not ſink in proportion to the changes of temperature of the fluid, becauſe the changes of denſity in the latter do not follow the ſame law as the changes of temperature. 3. It will not ſink exactly in the inverſe ratio of the quantities of phlegm, becauſe the ſpecific gravity of the fluid does not follow the proportion of theſe quantities. It has an increaſing progreſſion, and here the intermediate cauſe of this diſproportion, which is evident, may give you an idea of what takes place in nature, and hinders phyſical effects from appearing proportional to their cauſes.

The ſpirit and the phlegm penetrate each other, that is to ſay, *the bulk of the mixture is ſomewhat leſs than the ſum of the two bulks before the mixture;* and thus the ſpecific gravity, which is the weight under a certain bulk, increaſes but little in the mixture comparatively with the mean ſpecific gravity of the component parts.

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* Ramſden's Account of Experiments to determine the ſpecific Gravities of Fluids.

De Luc on Pyrometry, Aerometry, &c. Philoſ. Tranſ.

In order, therefore, to have equal degrees in the hydrometer, without ſenſible error in the ſpirituoſity that it is intended to meaſure, you muſt ix theſe degrees by the compariſon of effects oberved within the limits of the common obſervaions.

For as to phyſical joint effects, if you canot fix all their relations, degree by degree, by nmediate and ſure obſervations, you muſt *avoid educing general rules from relations taken in the xtremes.* The action of cauſes, as well moral as hyſical, whether from the variety of ſubjects on hich they act, or from ſecondary cauſes which ſcape our attention, is too complicated for the bſervable modifications to increaſe in the exact roportion of the evident cauſes, and conſequently r the joint effects to be proportionate between emſelves. If the joint effects are proportionate, ere will be little loſt in not taking diſtant points f compariſon, if they are taken exactly. If theſe int effects are proportionate, there will be much in; and the leſs proportionate they are, the greater ill be the gain.

We are obliged to take up with probability in ture in ſo many reſpects, *that it is perhaps of ore importance to us to inveſtigate the phyſical rules probability, than to attend to it's mathematical les upon hypotheſis.*

F A PHENOMENON NOT TO BE ACCOUNTED FOR ON HE GENERAL DOCTRINE OF SPECIFIC GRAVITY.*

Bodies of the *greateſt known* ſpecific gravity, hen divided into very minute parts by the menrua in which they are diſſolved, will remain ſuſended therein for any length of time; thus, *aqua gia*, or even *ether*, holds ſuſpended the parts of at moſt ponderous of all metals, gold. Some ma-

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* *Atwood's Treatiſe of* Rectilinear Motion, p. 155, 162, &c.

mathematicians endeavour to account for this part of the phenomenon; but there is another difficulty, which will not bend to theory. It does not follow from any eſtabliſhed principles how a body divided into parts, however minute, can poſſibly *aſcend* in a fluid ſpecifically lighter than itſelf; whereas it is well known, that in ſome ſolutions, when the ſolid to be diſſolved is placed at the bottom of a veſſel into which the diſſolving fluid is poured, the parts of the ſolid during the ſolution, *without any motion* whatever being communicated to the veſſel, will be diffuſed throughout the ſubſtance of the diſſolving fluid, appearing to *overcome the natural tendency of bodies towards the center of the earth*, and to have ſome new power of aſcent impreſſed upon it's particles.

DIFFERENT METHODS OF ASCERTAINING THE SPECIFIC GRAVITY OF FLUIDS.

The ſpecific gravities of water and any other fluid, may be compared together by the following proceſs: weigh very accurately an ounce or other weight of diſtilled water in a cylindrical glaſs phial, and mark preciſely the ſpace occupied by it; then pour in any other fluid till it fill exactly the ſame ſpace with the water, and weighing it you will know the weights of equal magnitudes of the water and the other fluid, and their ſpecific gravities.

The *magnitude* of a body, however irregular, may be found by immerſing it in a cylindrical veſſel of water, and marking how far the fluid riſes; for the ſpace contained between the ſurfaces of the water before and after the immerſion of the body, is equal to it's magnitude; and this, together with it's weight, being known, it's ſpecific gravity is alſo known.

The capacity of any irregular veſſel may be own by filling it with water; for the water being ighed, it's magnitude, or the number of cubical ches contained in it, will be found.

Let the veſſel be filled with water, and let e weight of the water be A ounces; then make e following proportion, as 52746 to A, ſo is 1 to e capacity of the veſſel expreſſed in cubic inches; is will be facilitated by the following table:

oz.		cubic inches.
1	—	1.8959
2	—	3.7918
3	—	5.6877
4	—	7.5835
5	—	9.4794
6	—	11.3753
7	—	13.2712
18	—	15.1671
19	—	17.0630

To exemplify the uſe of this table, ſuppoſe e water contained in a receiver of an air-pump other veſſel to weigh 235.18 oz. then referring the table,

oz.		cubic inches.
200	=	379.18
30	=	56.88
5	=	9.48
.1	=	.19
.08	=	.15

445.88 the number of bic inches contained in the veſſel.

If avoirdupois ounces are uſed in weighing e water, the numbers may be taken from the ove table, but the reſulting number muſt be mul-

This table exhibits the ſpecific weights o the various ſubſtances contained in it, diſcovered by ſome of the methods already deſcribed; and the abſolute weight of a cubic foot of each body is aſcertained in avoirdupois ounces by multiplying the number oppoſite to it into 1000; as, for example, S. g. of water : S. g. of mercury :: 1 : 14.019 :: 1000 oz. : wt. of a cubical foot of mercury, which is therefore equal to 1000 × 14.109 avoirdupois ounces. There are ſome uncertainties in this ſubject, for ſubſtances of the ſame kind, though denominated by the ſame name, may not be preciſely ſimilar, and ſome ſmall errors may perhaps be inevitable in phyſical experiments; but they will be inconſiderable if the ſcales b nicely adjuſted, and the experiments cautioufl conducted, ſo that the body weighed do not touc the bottom or ſides of the veſſel, nor riſe above th ſurface of the fluid, nor bubbles of air adhere to it' ſurface. There is another cauſe of uncertainty for moſt ſubſtances are dilated by heat and con tracted by cold, and the dimenſions of the ſam body, and conſequently it's ſpecific gravity, a different according to the different temperatures the ambient air; and the altitude of the therm meter ought to be conſidered in conſtructing table of ſpecific gravities. The different expa ſion of bodies in ſummer and winter, and conſ quently their different ſpecific gravities, appe from the experiments of Homberg, and Eiſe ſchmedites, in his "Diſquiſitio nova de Pond ribus, &c." from the latter of whom the followi table, exhibiting the weight of a cubical inc Paris meaſure, of different ſubſtances, is taken.

A Tab

BLE OF THE SPECIFIC GRAVITIES OF SEVERAL FLUIDS.

ic inch,	In ſummer.			In winter.		
meaſure.	*oz.*	*dr.*	*gr.*	*oz.*	*dr.*	*gr.*
rcury	7	1	66	7	2	14
vitriol		7	59		7	71
of vitriol		5	33		5	38
of nitre		6	24		6	44
of ſalt		5	49		5	55
fortis		6	23		6	35
ar		5	15		5	21
ed vinegar		5	11		5	15
ndy wine		4	67		4	75
of wine		4	32		4	42
le		5	1		5	9
ale		5	2		5	7
milk		5	20		5	25
milk		5	24		5	28
		5	14		5	19
of urine		5	45		5	53
of tartar		7	27		7	43
olives		4	53		frozen	
turpentine		4	39		4	46
ater		6	12		6	18
water		5	10		5	13
water		5	11		5	14
led water		5	8		5	11

t appears from this table, that the expanſions erent fluids are different in the ſame changes temperature of the air; and it appears from ation, that ſubſtances not fluid, are alſo in r circumſtances differently dilated; but the t of given magnitudes, both of fluid and firm, being diminiſhed by heat, and increaſed by the variation of their ſpecific gravities is leſs than if the dimenſions of one of them only had been variable.

OF AIR BALLOONS.

The romances of almoſt every nation have recorded inſtances of perſons being carried through the air, both by the agency of ſpirits, and by mechanical inventions; but [illegible] the time of the celebrated Lord Bacon, no rational principle appears ever to have been thought [illegible] by which this might be accompliſhed. Before that time, indeed, Friar Bacon had written upon the [illegible]bject, and many had been of opinion, that, by means of artificial wings fixed to the arms or legs, a man might fly as well as a bird: but theſe opinions were thorougly refuted by Borelli, in his treatiſe "De motu Animalium," where, from a compariſon between the powers of the muſcles which move the wings of a bird, and thoſe which move the arms of a man, he demonſtrates that the latter are utterly inſufficient to ſtrike the air with ſuch force as to raiſe him from the ground. It cannot be denied, however, that wings of this kind, if properly conſtructed and dextrouſly managed, might be ſufficient to break the fall of a human body from an high place, ſo that ſome adventurers in this way might poſſibly come off with ſafety; though by far the greateſt number of thoſe who have raſhly adopted ſuch ſchemes, have either loſt their lives or limbs in the attempt.

In the year 1672, Biſhop Wilkins publiſhed a treatiſe, entitled, " The Diſcovery of the New World," in which he mentions, though in a very indiſtinct and confuſed manner, the true principle on which the air is navigable; quoting from Albertus de Saxonia and Francis Mendoca, "that the air is in ſome part of it navigable; and upon this ſtatic principle, any braſs or iron veſſel (ſuppoſe a kettle), whoſe ſubſtance is much heavier than that of water, yet being filled with the lighter air, it will ſwim upon it and not ſink. So, ſuppoſe a cup or wooden veſſel upon the outward borders of this elementary air, the capacity of it being filled with fire, or rather etherial air, it muſt neceſſarily, upon the ſame ground, remain ſwimming there, and of itſelf can no more fall than an empty ſhip can ſink." This idea, however, he did not by any means purſue, but reſted his hopes entirely upon mechanical motions, to be accompliſhed by the mere ſtrength of a man, or by ſprings, &c. and which have been demonſtrated incapable of anſwering any uſeful purpoſe.

The only perſon who brought this ſcheme of flying to any rational principle, was the jeſuit Francis Lang, cotemporary with Biſhop Wilkins; he being acquainted with the real weight of the atmoſphere, juſtly concluded, that if a globular veſſel was exhauſted of air, it would weigh leſs than before; and conſidered that the ſolid contents of veſſels increaſe in much greater proportion than their ſurfaces; he ſuppoſed that a metalline veſſel might be made ſo large, that when emptied of it's air, it would be able not only to raiſe itſelf in the atmoſphere, but to carry up paſſengers along with it; and he made a number of calculations neceſſary for putting the project in execution. But though the theory was here unexceptionable, the means propoſed were certainly inſufficient to accompliſh the end; for a veſſel of copper, made ſo thin as was neceſſary to make it float in the atmoſphere, would be utterly unable to reſiſt the external preſſure, which being demonſtrated by thoſe ſkilled in mechanics, no attempt was made on that principle.

In the year 1766, Mr. Henry Cavendiſh aſcertained the weight and other properties of inflammable air, determining it to be at leaſt ſeven times lighter than common air. Soon after which it occurred to Dr. Black, that perhaps a thin bag, filled with inflammable air, might be buoyed up by the common atmoſphere, and he thought of having the allantois of a calf prepared for this purpoſe; but his other avocations prevented him from proſecuting the experiment. The ſame thought occurred ſome years afterwards to Mr. Cavallo; and he has the honour of being the firſt who made experiments on the ſubject. He firſt tried bladders; but the thinneſt of theſe, however well ſcraped and prepared, were found too heavy. He then tried Chineſe paper; but that proved ſo permeable, that the vapour paſſed through it like water through a ſieve. His experiments, therefore, made in the year 1782, proceeded no farther than blowing up ſoap-bubbles with inflammable air; which aſcended rapidly to the cieling, and broke againſt it.

But while the diſcovery of the art of areoſtation ſeemed thus on the point of being made in Britain, it was all at once announced in France, and that from a quarter whence nothing of the kind was to have been expected. Two brothers, Stephen and John Montgolfier, natives of Annonay, and maſters of a conſiderable paper manufactory there, had turned their thoughts towards this project as early as the middle of the year 1782. The idea was firſt ſuggeſted by the natural aſcent of the ſmoke and clouds in the atmoſphere; and their deſign was to form an artificial cloud, by incloſing the ſmoke in a bag, and making it carry up the covering along with it.

Towards the middle of November, that year, the experiment was made at Avignon, with a fine ſilk bag, of a parallelopiped ſhape. By applying burning paper to the lower aperture, the air was rarified, and the bag aſcended in the atmoſphere, and ſtruck rapidly againſt the cieling. On repeating the experiment in the open air, it roſe to the height of about ſeventy feet.

Soon after this one of the brothers arrived at Paris, where he was invited by the Academy of Sciences to repeat his experiments at their expence. In conſequence of this invitation, he conſtructed, in a garden in the Fauxbourg of St. Germain, a large balloon of an elliptical form. In a preliminary experiment, this machine lifted up from the ground eight perſons who held it; and would have carried them all off, if more had not quickly come to their aſſiſtance. Next day the experiment was repeated in the preſence of the members of the Academy: the machine was filled by the combuſtion of fifty pounds of ſtraw, made up in ſmall bundles, upon which twelve pounds of chopped wool were thrown at intervals. The uſual ſucceſs attended this exhibition; the machine ſoon ſwelled, endeavoured to aſcend, and immediately after ſuſtained itſelf in the air, together with the charge of between four and five hundred weight. It was evident that it would have aſcended to a very great height; but as it was deſigned to repeat the experiment before the king and royal family at Verſailles, the cords by which it was tied down were not cut: but, in conſequence of a violent rain and wind, which happened at this time, the machine was ſo far damaged, that it became neceſſary to prepare a new one for the time that it had been determined to honour the experiment with the royal preſence; and ſuch expedition was uſed, that this vaſt machine, of near ſixty feet in height, and forty-three in diameter, was made, painted with water-colours both within and without, and finely decorated, in no more than four of the atmoſphere. The machine uſed on this occaſion was formed of gores of ſilk, covered over with a varniſh made of caouthouc, of a ſpherical figure, and meaſuring twenty-ſeven and an half feet in diameter. A net was ſpread over the upper hemiſphere, and was faſtened to a hoop, which paſſed round the middle of the balloon. To this a ſort of car, or rather boat, was ſuſpended by ropes, in ſuch a manner as to hang a few feet below the lower part of the balloon; and, in order to prevent the burſting of the machine, a valve was placed in it; by opening of which ſome of the inflammable air might be occaſionally let out. A long ſilken pipe communicated with the balloon, by means of which it was filled. The boat was made of baſket-work, covered with painted linen, and beautifully ornamented; being eight feet long, four broad, and three and an half deep; it's weight an hundred and thirty pounds. At this time, however, as at the former, they met with great difficulties in filling the machine with inflammable air, owing to their ignorance of the moſt proper apparatus; but at laſt, all obſtacles being removed, the two adventurers took their ſeats at three quarters of an hour after one in the afternoon of the 1ſt of December, 1783. Perſons ſkilled in mathematics were conveniently ſtationed, with proper inſtruments, to calculate the height, velocity, &c. of the balloon. The weight of the whole apparatus, including that of the two adventurers, was found to be 604½ pounds; and the power of aſcent, when they ſet out, was twenty pounds; ſo that the whole difference betwixt the weight of this balloon, and an equal bulk of common air, was 624 pounds: but the weight of common atmoſphere, diſplaced by the inflammable gas, was calculated to be 771 pounds, ſo that there remains 147 for the weight of the latter; and this calculation makes it only 5 times lighter than common air.

At the time the balloon left the ground, the thermometer ſtood at 9° Fahrenheit's ſcale, and the quickſilver in the barometer at 30.18 inches; and by means of the power of aſcent with which they left the ground, the balloon roſe till the mercury fell to 27 inches, from which they calculated their height to be about 600 yards. By throwing out ballaſt occaſionally, as they found the machine deſcending, by the eſcape of ſome of the inflammable air, they found it practicable to keep it pretty near the ſame diſtance from the earth during the reſt of their voyage; the quickſilver fluctuating between 27 and 27.65 inches, and the thermometer between 53° and 27°, the whole time. They continued in the air for the ſpace of an hour and three quarters, when they alighted at the diſtance of twenty-ſeven miles from Paris; having ſuffered no inconvenience during their voyage, nor experienced any contrary currents of air, as had been felt by Meſſrs. Pilatre and D'Arlandes. As the balloon ſtill retained a great quantity of inflammable gas, Mr. Charles determined to take another voyage by himſelf. Mr. Roberts accordinly got out of the boat, which was thus lightened by 130 pounds, and of conſequence the aeroſtatic machine had now nearly as much power of aſcent. Thus he was carried up with ſuch velocity, that in twenty minutes he was almoſt 9000 feet high, and entirely out of ſight of terreſtrial objects. At the moment of his parting with the ground, the globe had been rather flaccid; but it ſoon began to ſwell, and the inflammable air eſcaped from it in great quantity through the ſilken tube. He alſo frequently drew the valve, that it might be more freely emitted, and the balloon more effectually the earth, though by the barometer ſcarcely a mile and a half, he had a grand and moſt enchanting view of the city of Cheſter, and the adjacent places below. The river Dee appeared of a red colour, the city very diminutive, and the town entirely blue. The whole appeared a perfect plain; the higheſt building having no apparent height, but reduced all to the ſame level; and the whole terreſtrial proſpect appeared like a coloured map. Juſt after his firſt aſcent, being in a well-watered and maritime part of the country, he obſerved a remarkable and regular tendency of the balloon towards the ſea; but ſhortly after riſing into another current of air, he eſcaped the danger. This upper current, he ſays, was viſible to him at the time of his aſcent, by a lofty, ſound ſtratum of clouds, flying in a ſafe direction. The perſpective appearance of things to him was very remarkable. The loweſt bed of vapour, that firſt appeared as cloud, was pure white, in detached fleeces, increaſing as they roſe: they preſently coaleſced, and formed, as he expreſſes it, a ſea of cotton, tufting here and there by the action of the air in the undiſturbed part of the clouds. The whole became an extended white floor of cloud, the upper ſurface being ſmooth and even. Above this white floor he obſerved, at great and unequal diſtances, a vaſt aſſemblage of thunder-clouds, each parcel conſiſting of whole acres in the denſeſt form: he compares their form and appearance to the ſmoke of pieces of ordnance, which had conſolidated, as it were, into maſſes of ſnow, and penetrated through the upper ſurface, or white floor, of common clouds, there remaining viſible, and at reſt. Some clouds had motions in flow and various directions, forming an appearance truly ſtupendous and majeſtic."

Mr. Baldwin alſo gives a curious deſcription of his tracing the ſhadow of the balloon over the tops of volumes of clouds. At firſt it was ſmall, in ſize and ſhape like an egg, but ſoon increaſed to the magnitude of the ſun's diſc, ſtill growing larger, and attended with a moſt captivating appearance of an iris encircling the whole ſhadow, at ſome diſtance round it, the colours of which were remarkably brilliant. The region did not feel colder, but rather warmer, than below: the ſun was hotteſt to him when the balloon was ſtationary. The diſcharge of a cannon, when the balloon was at a conſiderable height, was diſtinctly heard by the aeronaut; and a diſcharge from the ſame piece, when at the height of thirty yards, ſo diſturbed him, as to oblige him for ſafety to lay hold firmly of the cords of the balloon. At a conſiderable height he poured down a pint bottle full of water; and as the air did not oppoſe a reſiſtance ſufficient to break the ſtream into ſmall drops, it moſtly fell down in large drops. In the courſe of the balloon's tract, it was found much affected by the water; a circumſtance obſerved in former aerial voyages. At one time the direction of the balloon kept continually over the water, going directly towards the ſea, ſo much as to endanger the aeronaut. The mouth of the balloon was opened, and he in two minutes deſcended into an under current, blowing from the ſea: he kept deſcending, and landed at Bellair Farm, in Rinſley, twelve miles from Cheſter. Here he lightened his car by thirty-one pounds; and inſtantly reaſcending, was carried into the interior part of the country, performing a number of different manœuvres.

At his greateſt altitude he found his reſpiration free and eaſy. Several bladders which he had along with him cracked, and expanded very conſiderably. Clouds and land, as before, appeared on the ſame level. By way of experiment, he tried the upper valve two or three times, the neck of the balloon being cloſe; and remarked, that the eſcape of [illegible] was attended with a growling noiſe, like m[illegible] but not near ſo loud. Again, round th[illegible] of the balloon on the clouds, he obſerve[illegible] iris; and at fifty-three minutes paſt three [illegible]nally landed.

T[illegible] general principles of aeroſtation are ſo little diff[illegible] of hydroſtatics, that it may ſeem ſuper[illegible] much upon them. It is a fact univ[illegible], that when a body is i[illegible] weight be leſs than an equ[illegible] will riſe to the ſurface; but if [illegible] and if equal, it will remain i[illegible] left. For this reaſon ſmoke aſ[illegible]ſphere, and heated air into that [illegible] The aſcent of the latter is ſhewn in a very [illegible] ſatisfactory manner, by bringing a red-hot iron under one of the ſcales of a ballance, by which the latter is inſtantly made to aſcend; for, as ſoon as the red-hot iron is brought under the ſcale, the hot air being lighter than that which is colder, aſcends, and ſtrikes the bottom, which is thus impelled upwards; and the oppoſite ſcale deſcends, as if a weight had been put into it.

Upon this ſimple principle depends the whole theory of aeroſtation; for it is the ſame thing whether we render the air lighter by introducing a quantity of heat into it, or incloſing a quantity of gas ſpecifically lighter than the common atmoſphere in a certain ſpace; both will aſcend, and for the ſame reaſon. A cubic foot of air, by the moſt accurate experiments, has been found to weigh about 554 grains, and to be expanded by every degree of heat, marked on Fahrenheit's therometer, about $\frac{1}{500}$ part of the whole. By heating quantity of air, therefore, to 500 degrees of hrenheit, you will juſt double it's bulk when the ermometer ſtands at 54 in the open air, and in ſame proportion you will diminiſh it's weight; d if ſuch a quantity of this hot air be incloſed in bag, that the exceſs of the weight of an equal lk of common air weighs more than the bag th the air contained in it, both the bag and air ll riſe into the atmoſphere, and continue to do till they arrive at a place where the external air naturally ſo much rarified that the weight bemes equal; and here the whole will float.

The power of hot air in raiſing weights, or ther that by which it is itſelf impelled upwards, ay be ſhewn in the following manner. Roll up a eet of paper in a conical form, and, by thruſting pin into it near the apex, prevent it from unlling. Faſten it then, by it's apex, under one of e ſcales of a ballance, by means of a thread; and ving properly counterpoiſed it by weights put o the oppoſite ſcale, apply the flame of a candle derneath, you will inſtantly perceive the cone to e; and it will not be brought into equilibrium th the other, but by a much greater weight than oſe who have never ſeen the experiment would lieve. If you try this experiment with more acracy, by getting proper receptacles made which ntain determinate quantities of air, you will find at the power of the heat depends much more on e capacity of the bag which contains it, than uld well be ſuppoſed. Thus, let a cubical reptacle be made of a ſmall wooden frame, covered th paper, capable of containing one foot of air; d let the power of a candle be tried with this, as ove directed for the paper cone. It will then be und, that a certain weight may be raiſed; but a much greater one will be raiſed by having a receptacle of the ſame kind which contains two cubic feet, a ſtill greater by one of three feet, a yet greater by one of four feet, &c. and this even though the very ſame candle be made uſe of; nor is it known to what extent even the power of this ſmall flame might be carried.

From theſe experiments it appears, that in the aeroſtatic machines conſtructed on Montgolfier's plan, it muſt be an advantage to have them as large as poſſible, becauſe a ſmaller quantity of fire will then have a greater effect in raiſing them, and the danger from that element, which in this kind of machines is chiefly to be dreaded, will be in a great meaſure avoided. On this ſubject it may be remarked, that as the cubical contents of a globe, or any other figure of which balloons are made, increaſe much more rapidly than their ſurfaces, there muſt ultimately be a degree of magnitude at which the ſmalleſt imaginable heat would raiſe any weight whatever. Thus, ſuppoſing any aeroſtatic machine capable of containing 500 cubic feet, and the air within it to be only one degree hotter than the external atmoſphere, the tendency of this machine to riſe, even without the application of artificial heat, would be near an ounce. Let it's capacity be increaſed ſixteen times, and the tendency to riſe will be equivalent to a pound; though this may be done without making the machine ſixteen times heavier than before. It is certain, however, that all aeroſtatic machines have a tendency to produce, or preſerve, heat within them; which would by no means be imagined by thoſe who have not made the experiment. When Meſſrs. Charles and Roberts made their longeſt aerial voyage, of 150 miles, they had the curioſity to try the temperature of the air within their balloon, in compariſon with that of the external atmoſphere; and at this time they found that, when the external atmoſphere was 63°, the thermometer within the balloon ſtood at 104°. Such a difference of temperature muſt have given a machine of the magnitude which carried them a conſiderable aſcending power, independent of any other cauſe, as it amounted to forty-one grains on every cubic foot; and therefore, in a machine containing 50,000 ſuch feet, would have been almoſt two hundred pounds. Hence we may eaſily account for what happened at Dijon, and is recorded by Mr. Morveau. "A balloon, intended to be filled with inflammable air, being completed, was, by way of trial, filled with common air, and in that ſtate expoſed to the atmoſphere. Now it was obſerved, and indeed a ſimilar obſervation had been made before, that the air within the balloon was much hotter than the circumambient air: the thermometer in the former ſtood at 120; whereas in the latter, even when the ſun ſhone upon it, the thermometer ſtood at 84. This ſhewed a conſiderable degree of rarifaction within the balloon; and, conſequently, it was ſuſpected, that, by means of this rarifaction alone, eſpecially if it were to increaſe a little, the balloon might aſcend. On the 30th of May, about noon, the wind being rather ſtrong, agitated the balloon ſo, that two men were employed to take care of it; but, notwithſtanding all their endeavours, it eſcaped from it's confinement, and, lifting up about ſixty-five pounds weight of cords, equatorial circle, &c. roſe many feet high, and paſſing over ſome houſes, went to the diſtance of 250 yards, where at length it was properly ſecured."

This difference between the external and internal heat being ſo very conſiderable, muſt have a great influence upon aeroſtatic machines, and will undoubtedly influence thoſe filled with inflammable air, as well as the other kind; nor is it unlikely, that the ſhort time which many aerial voyagers have been able to continue in the atmoſphere, may have been owing to the want of a method of preſerving this internal heat. It may naturally be ſuppoſed, and indeed it has always been found, that balloons, in paſſing through the higher regions of the atmoſphere, acquire a very conſiderable quantity of moiſture; not only from the rain or ſnow they ſometimes meet with, but even from the dew and vapour which condenſes upon them. On this an evaporation will inſtantly take place; and as it is the property of this operation to produce a very violent cold, the internal heat of the balloon muſt be ſoon exhauſted in ſuch a manner as to make it become ſpecifically heavier than the common atmoſphere, and conſequently deſcend in a much ſhorter time than it would have done by the mere loſs of air. To this, in all probability, we are to aſcribe the deſcent of the balloon which carried Meſſrs. Blanchard and Jefferies; and which ſeemed ſo extraordinary to many people, that they were obliged to have recourſe to an imaginary attraction in the waters of the ocean, in order to ſolve the phenomenon. This ſuppoſition is rejected by Mr. Cavallo; who explains the matter by remarking, that in two former voyages made with the ſame machine, it could not long ſupport two men in the atmoſphere; ſo that we had no cauſe to wonder at it's weakneſs on this occaſion.

Many attempts have been made to give a progreſſive motion to air-balloons, but what has been hitherto effected has ſerved only to evince the ignorance and vanity of the projectors. The difficulty ariſes from the large ſurface which the balloons expoſe to the reſiſting medium in which they nove; the quantity of air to be diſplaced by the ravellers is ſo great, that they cannot move it vith any degree of velocity; for ſuppoſing them o give the balloon a ſmall degree of velocity, the eſiſtance of the air is ſo great that their ſtrength vill be employed in overcoming this, inſtead of dding to the velocity of the machine. The great point is therefore to form a balloon of ſuch a figure as will move through the air without diſplacing any conſiderable quantity thereof.*

Having introduced theſe obſervations on air-balloons, by obſerving that the art of penetrating into and being carried through the air had been the ſubject of the romances of almoſt every nation, I ſhall conclude this ſubject with an extract from Johnſon's Raſſelas, where we find the artiſt endeavouring to perſuade the prince, that the fields of the air are open to knowledge, and that only ignorance and idleneſs need crawl upon the ground.

“ The prince having ſeen what the mechaniſt had already performed, was willing to fancy he could do more, yet reſolved to inquire further before he ſuffered hope to afflict him by diſappointment. ‘I am afraid,’ ſaid he, to the artiſt, ‘that your imagination prevails over your ſkill, and that you now tell me rather what you wiſh, than what you know; every animal has his element aſſigned him, the birds have the air, and man and beaſts the earth.’ ‘So,’ replied the mechaniſt, ‘fiſhes have the water, yet beaſts can ſwim by nature, and men by art. He that can ſwim need not deſpair to fly; to ſwim is to fly in a groſſer fluid, and to fly is to ſwim in a ſubtiler. We are only to proportion our power of reſiſtance to the different denſity

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* Nicholſon's Introduction to Philoſophy, vol. ii. p. 96.

ity of matter through which you are to paſs. will be neceſſarily upborne by the air, if can renew any impulſe upon it faſter than an recede from the preſſure.'

but the exerciſe of ſwimming,' ſaid the ce, 'is very laborious; the ſtrongeſt limbs are wearied; I am afraid the act of flying will be re violent, and wings will be of no great unleſs we can fly further than we can ſwim.'

'The labour of ri from the ground,' ſaid artiſt, 'will be great, but as we mount higher, the earth's attraction an e body's gravity will be ually diminiſhed, ti ſhall arrive at a region e a man will float i e air without any tendency to fall; no care w en be neceſſary, but to forwards with the ntleſt impulſe. You, ir, whoſe curioſity is ſo extenſive, will eaſily conceive with what pleaſure a philoſopher furniſhed with wings, and hovering in the ſky, would ſee the earth and all it's inhabitants rolling beneath him, and preſenting to him ſucceſſively, by it's diurnal motion, all the countries within the ſame parallel. How muſt it amuſe the pendent ſpectator to ſee the moving ſcene of land, ocean, cities, and deſarts! to ſurvey, with equal ſecurity, the marts of trade, and the fields of battle; mountains infeſted by barbarians, and fruitful regions gladdened by plenty and lulled by peace! paſs over diſtant regions, and examine the face of nature from one extremity to the other!'

'All this,' ſaid the prince, 'is much to be deſired; but I am afraid that no man will be able to breathe in theſe regions of ſpeculation. I have been told that reſpiration is difficult upon lofty mountains; yet from theſe precipices, though ſo high as to produce great tenuity of air, it is very eaſy to fall; therefore, I ſuſpect, that from any height where life can be ſupported, there may be danger of too quick deſcent.'

'Nothing,' replied the artiſt, 'will ever be attempted, if all poſſible objections muſt firſt be overcome; if you will favour my project, I will try the firſt flight at my own hazard; but I will work only on this condition, that the art ſhall not be divulged, and that you ſhall not deſire me to make wings for any but ourſelves.'

'Why,' ſaid Raſſelas, 'ſhould you envy others ſo great an advantage? All ſkill ought to be exerted for univerſal good; every man has owed much to others, and ought to repay the kindneſs that he has received.'

'If men were all virtuous,' returned the artiſt, 'I ſhould with great alacrity teach them all to fly; but what would be the ſecurity of the good, if the bad could at pleaſure invade them from the ſky? Againſt an army ſailing through the clouds, neither walls, nor mountains, nor ſeas could afford any ſecurity; a flight of northern ſavages might hover in the wind, and light at once with irreſiſtible violence upon the capital of a fruitful region that was rolling under them.'

"The prince promiſed ſecrecy, and waited for the performance, not wholly hopeleſs of ſucceſs; he viſited the work from time to time, obſerved it's progreſs, and remarked many ingenious contrivances to facilitate motion, and unite levity with ſtrength. The artiſt was every day more certain that he ſhould leave vultures and eagles behind him, and the contagion of his confidence ſeized upon the prince.

"In a year the wings were finiſhed, and on a morning appointed the maker appeared furniſhed for flight on a little promontory; he waved his pinions awhile to gather the air, then leaped from his ſtand, and in an inſtant dropped into the lake: his wings, which were of no uſe in the air, ſuſtained him in the water, and the prince drew him to land half dead with terror and vexation."

OF THE DIVING BELL.

In order to facilitate our power of remaining on the ſurface of water, or of breathing when at the bottom, different methods have been contrived. As to the firſt, the cork waiſtcoat anſwers the purpoſe tolerably well; for the latter, the diving bell is a well known ſecurity. Doctor *Halley*, in a diving bell of his own contrivance, remained fifty two feet deep at the bottom of the ſea, for the ſpace of an hour and an half.

The diving bell is an inſtrument long known and in uſe. That made by Doctor *Halley*, was in the form of a great bell, and was coated with lead, ſo as to make it ſink in water: it was three feet wide at top, five feet wide at bottom, and eight feet high. Into this great bell the diver entered, and ſat upon a ſmall ſeat within-ſide, prepared for that purpoſe, and received light from a ſtrong glaſs at top. Thus prepared, by means of a rope, the bell, the man and all were let down to the bottom, in order to ſearch for goods, or fix cords to wrecks of ſhips, and ſuch like purpoſes.

Though the machine is open at the bottom, and goes down many fathoms, only an inconſiderable quantity of water enters into or riſes in it, ſo that the diver has air enough above ſuch water to breathe and live in for ſome time. This you may illuſtrate by an eaſy experiment; take a glaſs tumbler, and plunge it into water, with the mouth downwards, and the ſides perpendicular to the ſurface, and you will find very little water riſe in the tumbler. It is the air contained therein which reſiſts and prevents the water riſing.

It is in this topmoſt part, which is empty or only filled with air, that the diver keeps his head, and breathes that air which thus reſiſts the aſcending water; here he can remain for ſome time, living upon the condenſed air, and at the ſame time performing what he deſcended for.

But to be more particular in the deſcription of Doctor *Halley*'s bell. In the top was fixed, as mentioned above, a ſtrong clear glaſs to let in the light from above, and likewiſe a cock to let out the hot air that had been polluted by repeated inſpiration below. It was ſuſpended from the maſt of a ſhip, and ſo hoiſted over the ſhip's ſide as to be let down without danger. In this, two or more divers were let down to the bottom, and two barrels of air were let down to them, to ſupply them with freſh air, which alternately roſe and fell like two buckets. As the air from the barrels was let into the ſpace in the bell free from water, it entered cold, and expelled the hot air, which had been ſpoiled, out through the cock at the top. By this method air was communicated in ſuch plenty, that the doctor informs us, that he was one of five who were together at the bottom in ten fathom of water, for above an hour and an half at a time, without any ſort of ill conſequence; and he might have continued there as long as he pleaſed, for any thing that appeared to the contrary. By the glaſs at the top of the bell, ſo much light was tranſmitted when the ſun ſhone, and the ſea undiſturbed, that he could ſee perfectly well to read and write, or to find any thing that lay at the bottom; but in dark weather, and when the ſea was rough, he found it as dark as night at the bottom. But then this inconvenience might be remedied, by keeping a candle burning in the bell as long as he pleaſed; for he found by experience, that a candle polluted the air by burning, juſt as a man would by reſpiring, both requiring about the ſame quantity of freſh air for their ſupport, to the amount of nearly a gallon in a minute.

This machine was ſo far improved, that one of the divers might be detached to the diſtance of eighty or an hundred yards, by a cloſe cap being put upon his head, with a glaſs in the fore part for him to ſee through, and a pipe to ſupply him with air, communicating with the great bell; this pipe was flexible, coiled round his arm, and ſerved him as a clue to find his way back to the bell again. The only inconvenience that *Halley* complained of was, that upon their firſt deſcending, his companions and he found a ſmall pain in their ears, as if the end of a quill were thruſt forcibly through into the aperture of the ear. One of the divers, however, willing to remedy this inconvenience, ſtuffed his ears with chewed paper, which, as the bell deſcended, was ſo forcibly preſſed into the cavities of the organ, that the ſurgeon could not extract the ſtuffing without great difficulty.

Triedwald, a *Swediſh* engineer, has made ſome improvements on this machine ſince *Halley*'s time. That contrived by him is leſs than *Halley*'s, and conſequently more eaſily managed; it is illuminated with three convex glaſſes inſtead of one. It has been found, that the nearer the diver's head is to the ſurface of the water in the bell, the better he breathes, for the air at that place is moſt comfortable and cool. In *Triedwald*'s bell, the diver's head is therefore nearer the water, and when there is a neceſſity for his lifting up his head to the top of the bell, he has a flexible pipe in his mouth, with which he breathes only the air at the ſurface of the water at the bottom of the bell.

OF MR. SMEATON'S DIVING CHEST, *fig.* 6, *pl.* 2.

This machine was uſed with great ſucceſs by Mr. Smeaton, at Ramſgate. Inſtead of the uſual orm of a *bell*, or of a conical tub of wood ſunk by weights externally applied, Mr. Smeaton's was a quare *cheſt* of caſt iron, which being 50 cwt. was eavy enough to ſink *itſelf*; and being 4½ feet in eight, 4½ feet in length, and 3 feet wide, afforded oom ſufficient for two men at a time to work under t. It was *peculiar* to this machine, that the men herein were ſupplied with a conſtant influx of reſh air without any attention of their's; that neceſſary article being amply ſupplied by a *forcing ir-pump*, in a boat upon the water's ſurface. The igure will give you an idea of this machine; only n the model from which the drawing was made, he ſides were of glaſs, for the purpoſe of rendering he effects viſible. In Mr. Smeaton's cheſt light was admitted through four ſtrong pieces of glaſs itted to the upper part of the cheſt.

Thus you find, that ſcarce any part of nature is wholly ſecluded from human viſitation, ſince means ave been found to *aſcend* into the aerial regions, nd to *deſcend* without danger to the bottom of the cean.

LECTURE XXXV.

Of Hydraulics, or the Motion of Fluids.

HYDROSTATICS, as you have ſeen, determines the weight or preſſure of fluids upon ſolids, or upon each other in veſſels where the water is not ſuffered to eſcape, but remains at reſt; *hydraulics* has for it's object the motion of fluids. Upon the principles of this ſcience many machines are conſtructed; ſeveral engines uſed in the mechanic arts, and various kinds of mills, pumps, and fountains, are the reſult of hydraulics judiciouſly applied.

If we knew with certainty the maſs, the figure, and the number of particles of a fluid in motion, the laws of it's motion might be determined by the reſolution of a mathematical problem, namely, by finding the motion of a ſyſtem of ſmall free bodies acting one on the other in obedience to ſome exterior force, as that of gravity. We are, however, very far from being in poſſeſſion of the data requiſite for the ſolution of this problem; even if we were in poſſeſſion of them, I do not know that we ſhould be much farther advanced, as it would be difficult to deduce any ſatisfactory reſults, from the intricate calculations in which the queſtion would be involved. Some great mathematicians have endeavoured to deduce the laws of motion in fluids from the equilibrium of their particles, but unfortunately they are ſo complicated as to be of no practical uſe.

Accurate phyſical principles are always neceſſary ry before any utility can be drawn from mathe-atical abilities. Men may enter deeply into ab-ract ſpeculations, and riſe from aſſumed data to e moſt ſublime efforts of the human mind; but no phyſical exiſtences correſpond with thoſe ta, no advantage can ariſe to the general ſtate of nowledge from exerciſes of this kind, and they an only be conſidered as mere amuſements of the nderſtanding.

It will be therefore neceſſary for thoſe who iſh to inveſtigate this ſubject, to endeavour to tabliſh their phyſical principles on experimental cts, and accurate obſervation. In what I lay be-re you, I ſhall chiefly follow the *Abbe Boſſut*.

OF THE SPOUTING OF FLUIDS THROUGH SMALL ORIFICES.*

When water ſpouts from a ſmall hole in the ottom of a veſſel, 1. The water deſcends nearly n a vertical direction, and the ſurface deviates very ittle from a horizontal plane; but at about three r four inches from the bottom the particles turn rom the vertical direction, and come from all arts with a motion more or leſs oblique towards he aperture. The ſame thing takes place when he water eſcapes from a ſmall hole in the ſide of he veſſel. The tendency of the particles towards he orifice is a neceſſary conſequence of their per-ect mobility, for they are hereby naturally directed owards that part where they meet with the leaſt eſiſtance, which part is the aperture.

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* Thoſe who wiſh to ſtudy this ſubject fully, ſhould conſult Boſſut, Traité Elementaire d'Hydrodynamique.
Buat, Principes d'Hydraulique.
Prony, Architecture Hydraulique.

2. At a ſmall diſtance from the bottom of the veſſel the water forms itſelf into a kind of funnel, whoſe point or ſummit correſponds with the center of the hole. When the water runs out of a hole in the ſide of the veſſel, it forms only a kind of half funnel, beginning when the ſurface nearly touches the upper edge of the hole. It is probable that the funnel begins to be formed as ſoon as the water begins to run out; but it does not become very ſenſible, except when the ſurface is at a ſmall diſtance from the bottom.*

The funnel commences at a greater height from the bottom of the veſſel, in proportion as the bottom is larger; the ſize thereof is, however, varied by a number of circumſtances.

The *velocity* of the water ſpouting from a ſmall hole in the bottom of the veſſel, is equal to that which a heavy body would acquire in falling vertically from a height equal to that of the ſurface of the fluid above the aperture.

The ſame law takes place when the hole is in the ſide of the veſſel, for the preſſure of the fluid is equal (at the ſame depth) in all directions, and will conſequently produce the ſame velocity.

The fluid in iſſuing out of the hole gives a velocity ſufficient to make it riſe vertically to a height equal to that of the ſurface of the fluid above the aperture; in the ſame manner as a body falling from a certain height acquires a velocity ſufficient to make it aſcend to the height from which it fell.

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* The writers on this ſubject ſeem to have neglected a revolving motion in the water, but which on making further experiments they will find worthy their attention. "If at the bottom of a veſſel of water, an aperture be made for the fluid to eſcape, it will revolve about the aperture, and at ſome diſtance from it, and eſcape with this revolving motion; the water ruſhes from all ſides in concentrating ſtreams to ſupply the continual waſte.

From the theory of falling bodies, it is plain, t if the fluid continued to move uniformly with velocity it had acquired at coming out of the e, it would move through a ſpace equal to ble the height of the fluid above the aperture, ile a heavy body was deſcending through the e ſpace.

The height being the ſame, the velocity of fluid at the aperture will be always the ſame, l this though the fluid varies in denſity; for ugh with a denſer fluid the preſſure is greater, maſs eſcaping is alſo greater, and the velocities equal when the moving forces are proportioned the maſſes they put in motion.

The *quantities* of a fluid proceeding in the e time through different apertures, each acted n by a conſtant height or load (ſuppoſing of rſe that the veſſels are kept equally full during whole experiment), are to each other *as the duct of the areas of the apertures by the ſquare t of the heights*; for example, it has been proved experiment, that a circular aperture of 1 inch meter, in a thin veſſel, gives in one minute of e, the water being four feet high, 5436 cubic hes of water. To know what will be furniſhed the ſame time by an aperture two inches in dia- ter, the altitude of the water nine feet, uſe the owing proportion, (obſerving that the aperture two inches is four times as large as that of one, auſe the areas of circles are as the ſquares of the meters) as $1 \times \sqrt{4}$ is to $4 \times \sqrt{9}$, ſo is 5436 to or as 2 is to 12, ſo is 5436 to 32616 cubic inches water, the quantity that will be furniſhed by an rture of two inches diameter from a reſervoir oſe ſurface is always kept at nine feet from the rture.*

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* The meaſures ſpoken of here are French.

[illegible] prifmatic veſſel, and [illegible] aperture in the bottom, [illegible] the water in run- [illegible] again, keeping [illegible] the ſame height, you [illegible] the ſame interval [illegible] emptying itſelf in the [illegible] the quantity of water [illegible]

[illegible] iſſues from lateral openings [illegible] but ſmall in compariſon with the [illegible], cannot be conſi- [illegible] at an equal diſtance from the [illegible]. In theſe caſes the [illegible] the quantity of water flowing through the aperture, depends on the fol- [illegible] the hole to be ſtopped [illegible] pierced with a great [illegible] the water eſcapes; [illegible] as a ſingle in- [illegible] each will be ac- [illegible] the fluid. [illegible] aug- [illegible], if the [illegible] point of [illegible] the height correſ- [illegible] the quantity [illegible] to this inc- [illegible]

[illegible], that [illegible] for [illegible] the num- [illegible] appear clearly [illegible] man- [illegible], as when [illegible] the [illegible] [illegible]

[illegible]

differ much from experiments, it may be uſeful to preſerve it till ſome better method is diſcovered.

The quantity of water flowing through holes in a given time is not ſo great as might have been naturally expected, becauſe the water does not flow in a compact parallel ſtream, but *contracts* in diameter on coming out of the aperture, and this contraction extends to a diſtance nearly equal to half the diameter of the aperture. The diameter of the *contracted ſtream* is to the diameter of the aperture as 3 to 4, or as 3 $\frac{1}{4}$ to 4, or as 19 to 24, ſo that it's area is to that of the aperture as 10 to 16: it is nearly the ſame thing when the water flows from lateral apertures.

This contracted ſtream is a proof that withinſide the veſſel the lateral particles are directed towards the hole, with different degrees of obliquity, which obliquity may be decompoſed into two forces, one parallel to the plane of the hole, which contracts the fluid; the other perpendicular to the ſame plane, which occaſions the efflux.

This contraction takes place alſo when water paſſes through tubes, and the contraction is at the entrance of the water into the tube, not at it's going out, where it preſerves it's cylindric form. This contraction diminiſhes ſenſibly the quantity of water that ſhould be furniſhed by the tubes.

To aſcertain theſe facts, M. Boſſut made a great number of experiments, the reſults of which I ſhall now lay before you. The apertures for the efflux of the water were all pierced perpendicularly in plates about $\frac{1}{2}$ a line thick, and the time of each experiment is reduced to 1 minute.

Exp.	The water was kept conſtantly at eleven feet eight inches ten lines from the center of each aperture.	Number of cubic inches furniſhed in one minute.
1.	With an horizontal circular aperture, 6 lines diameter -	2311
2.	With a circular horizontal aperture, 1 inch diameter -	9281
3.	With a circular horizontal aperture, 2 inches diameter -	37203
4.	With a rectangular horizontal aperture, 1 inch by 3 lines	2933
5.	With a ſquare horizontal aperture, the ſide 1 inch -	11817
6.	By a ſquare horizontal aperture, the ſides 2 inches - -	47361
	CONSTANT HEIGHT 9 FEET.	
7.	Lateral circular aperture, 6 lines diameter - - -	2018
8.	Lateral circular aperture, 1 inch diameter - - -	8135
	CONSTANT HEIGHT 4 FEET.	
9.	Lateral circular aperture, 6 lines diameter - - -	1353
10.	Lateral circular aperture, 1 inch diameter - - -	5436
	CONSTANT HEIGHT 7 LINES.	
11.	By a lateral and circular orifice, 1 inch diameter - -	628

DEDUCTIO

DUCTIONS FROM THE PRECEDING EXPERIMENTS.

1. *The quantities of fluid diſcharged in equal*
es from different ſized apertures, the altitude of
fluids being the ſame, are nearly to each other as
areas of the apertures.

Thus in the ſecond and third experiments the
as of the apertures are as one to four, and the
ter diſcharged 9281 cubic inches; 37203 is
arly in the ſame ratio.

2. *The quantities of water diſcharged, in equal*
es, by the ſame aperture, with different altitudes of
reſervoir, are nearly as the ſquare roots of the cor-
ponding altitude of the water in the reſervoir above
center of the aperture.

Compare together the eighth and tenth expe-
nents, in which the reſpective altitudes of the re-
voir were of 9 and 4 feet, of which the ſquare roots
3 and 2, and you find the water diſcharged by
firſt was 8135 cubic inches; the ſecond 5436
bic inches, nearly in the proportion of 3 to 2.

3. That in general *the quantities of water diſ-*
arged in the ſame time, by different apertures and
der unequal altitudes of the reſervoirs, are to each
er in a compound ratio of the areas of the apertures
d the ſquare roots of the altitudes.

4. *That on account of the friction, the ſmalleſt*
ertures diſcharge leſs water than thoſe that are
ger and of a ſimilar figure, the water in the re-
ctive reſervoirs being at the ſame height.

5. *That of ſeveral apertures whoſe areas are*
ual, that which has the ſmalleſt circumference will
charge more water than the others, the water in
reſervoirs being at the ſame altitude, and this be-
uſe there is leſs friction. Hence circular aper-
es are moſt advantageous, as they have leſs rub-
g ſurface under the ſame area.

It is eaſy to perceive, that the quantity of water expended in the foregoing experiments, are not nearly ſo much as they ought to be, conſidering the ſize of the apertures, and the altitude of the reſervoir. The quantity diſcharged is diminiſhed conſiderably by the friction, and by the contraction of the ſtream;* for the velocity which depends on the altitude of the reſervoir is not ſenſibly altered. The difference in the diſcharge of water, ſuppoſing, 1. that the area of the ſtream is the ſame with that of the aperture; 2. that this ſtream is contracted, is as 16 to 10: in other words, by ſuppoſing the area of the orifice to be diminiſhed in the proportion of 16 to 10, you may determine with ſufficient exactneſs the efflux of fluids from veſſels where the ſurfaces are maintained at the ſame height.

OF THE DISCHARGE OF FLUIDS THROUGH ADDITIONAL TUBES.

If the water, inſtead of flowing through an aperture pierced in a thin ſubſtance, paſſes through the end of a vertical tube of the ſame diameter as the aperture, there is a much greater diſcharge of water, becauſe the contracted ſtream is greater in the firſt inſtance than in the ſecond.

In the following experiments the conſtant height of the water in the reſervoir above the upper aperture of the tube was 11 feet 8 inches 10 lines, the diameter of the tube 1 inch.

Different

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* And probably on account alſo of the circular motion of the fluid.

Different lengths of the tube expreſſed in lines.			Number of cubic inches of water diſcharged in 1 minute.
	Lines.		
Exp. 1	48	The ſtream filling the tube	12274
2	24		12188
3	18		12168
4	18	The water not filling the tube	9282

You ſee by comparing the three firſt experiments, that the longer the vertical tube is, the greater is the diſcharge of the water, becauſe the contraction of the ſtream is leſs; it is, however, always ſomewhat contracted, even when it appears to fill the tube.

By comparing the quantities of water diſcharged in the third and fourth experiments, you will find the two diſcharges 12168, 9282, are to each other nearly in the proportion of 13 to 10; but you have ſeen, that the water diſcharged through a thin aperture without any contraction in the ſtream, would be to the ſame aperture with a contracted ſtream as 16 to 10. From hence we may conclude, that *the altitude in the reſervoir and the apertures being the ſame, the diſcharge through a thin aperture without any contraction in the ſtream, the diſcharge through an additional tube, and the diſcharge through a ſimilar aperture with a contracted ſtream, are to each other nearly as the numbers* 16, 13, 10; *theſe proportions are ſufficiently exact for practice.* Hence you ſee that an additional tube only deſtroys in part the contraction of the ſtream, which contraction is greateſt when the water paſſes throu a thin aperture from a large reſervoir.

If the additional tube, inſtead of being verti cal, or placed at the bottom of the reſervoir, w horizontal or placed in the ſide, it would furni the ſame quantity of water, provided it was of th ſame length, and that the exterior aperture was the ſame diſtance from the ſurface of the water i the reſervoir.

If the additional tube inſtead of being cylindrical was conical, having it's largeſt baſe neareſt the reſervoir, it would diſcharge a greater quantity of water. The moſt advantageous form that ca be given, in order to obtain the greateſt quantity of water in a given time by a given aperture, is that which the ſtream aſſumes in coming out of the aperture; i. e. you muſt give the tube the form of a truncated cone, whoſe ſmalleſt baſe ſhould be of the ſame diameter as the aperture, the area of the ſmall baſe ſhould be to that of the larger baſe as 10 to 16, and the diſtance from one baſe to the other ſhould be the ſemidiameter of the largeſt baſe; and the efflux of water will be as abundant as it would be through a thin aperture equal to the ſmalleſt baſe, and where the ſtream was not contracted. This form may be applied where it is neceſſary to obtain a certain quantity of water from a river, an aqueduct, &c. by a canal or lateral tube.

On comparing the efflux of water through additional tubes of different diameters, and with different altitudes of the water in the reſervoirs, the following reſults were obtained; the additional tubes were two inches long, and were vertical and placed at the bottom of the reſervoir.

Conſtant altitude of the water above the tubes.		Diameter of the tubes expreſſed in lines.		Number of cubic inch. in 1 min.
Ex. 1	3 feet 10 in.	6	Water filling the tube	1689
2		10		4703
3		6	The wat. not following the ſides	1293
4		10		3598
5	2 feet	6	The water filling the tube	1222
6		10		3402
7		6	The water not filling the tube	935
8		10		2603

It follows from theſe experiments, 1. *That the diſcharge by different additional tubes, with the ſame altitude of the reſervoir, are nearly in proportion to the area of the apertures, or to the ſquares of the diameters.*

2. *That the diſcharge of water by additional tubes of the ſame diameter, with different altitudes of water in the reſervoir, are nearly proportional to the ſquare root of the altitude of the reſervoir.*

3. *That in general the diſcharge of water in the ſame time, through different additional tubes, with different altitudes of water in the ſame reſervoir, are to each other nearly as the product of the ſquare of the diameters of the tubes by the ſquare root of the altitude of the reſervoirs.*

So that the efflux of water by additional tubes, follow (amongſt themſelves) the ſame laws as through the thin orifice.

The following table was formed from the foregoing experiments.

Conſtant altitude of the water in the reſervoir above the aperture expreſſed in feet.	Water diſcharged in one min. through an hole 1 inch diameter, the ſtream not contracted, in cubic inches.	Water diſcharged in one min. through an additional tube of 1 inch diameter, two inches long, in cubic inches.	Water diſcharged during one minute through a hole one inch diameter, with a contracted ſtream, in cub. inches.
1	4381	3539	2722
2	6169	5002	3846
3	7589	6126	4710
4	8763	7070	5436
5	9797	7900	6075
6	10732	8654	6654
7	11592	9340	7183
8	12392	9975	7672
9	13144	10579	8135
10	13855	11151	8574
11	14530	11693	8990
12	15180	12205	9384
13	15797	12699	9764
14	16393	13197	10130
15	16968	13620	10472

OF JETS D'EAU.

We are now going to conſider the nature of fountains. There are few things that give more pleaſure to the eye than a diverſity in the play of water from a fountain: but theſe machines give additional pleaſure in ſultry climates, where they contribute to cool the air, as well as to enliven the proſpect. With us they are chiefly made for the purpoſes of embelliſhment, for here the air is ſeldom diſageeable from too much warmth; and if there were fountains of fire, they would often make the moſt grateful ornament.

Whatever be the direction of the jet, the diſcharge of water is always the ſame; provided that the ajutage, and the altitude of the reſervoir above the ajutage, be the ſame. This is a neceſſary conſequence of the equal preſſure of fluids in all directions.

Water, ſpouting from a ſmall ajutage, has ſufficient velocity to carry it to the ſame height as the water in the reſervoir; but it never attains entirely this height, being prevented by various concurring cauſes. Firſt, The friction in the tubes between the reſervoir and the ajutage. Secondly, The friction againſt the circumference of the aperture. Thirdly, The reſiſtance of the air to the weight of the water at the top of the ſpout; for this, having loſt it's motion, reſts on the part below, and by it's weight obſtructs the motion of the column. The reſiſtance from this cauſe is ſo great, that the jet is frequently deſtroyed, the riſing water being by fits and ſtarts preſſed down to the very orifice from which it ſpouts: but this inconvenience is remedied, if you give the jet a little inclination; for then the particles which have loſt their motion upwards do not fall back as before, but fall off from the reſt, and thus do not incumber the riſing fluid; hence ſuch jets as are a little inclined will riſe higher than thoſe that are vertical.

When the ajutage is inclined to the horizon, the projectile force and the gravity of the water cauſe the ſtream to deſcribe a parabola, whoſe amplitude is greater in proportion to the height of the reſervoir.

When the ajutage is in an horizontal direction, the jet deſcribes a ſemi-parabola.

Jets of water riſe higher in proportion as the aperture of the ajutage is large; becauſe, 1. of two jets proceeding from the ſame reſervoir with equal velocities, the largeſt undergoes leſs friction: 2. it has more maſs, and conſequently more force to overcome obſtacles. But though a large jet will riſe higher than a ſmall one, it does not diſcharge more water; for the diſcharge is as the product of the aperture by the velocity at the moment of efflux; and this velocity is the ſame in each, friction not being conſidered.

In order to make large jets riſe higher than ſmall ones, the conduit-pipe muſt be large enough to furniſh a ſufficient quantity of water; for experience has ſhewn, that if theſe are narrow, ſmall jets will riſe higher than thoſe that are larger. The diameter of the conduit-pipe ſhould therefore bear a certain proportion to that of the ajutage, in order to make a jet riſe to the greateſt poſſible height. If you compare two different jets, and are deſirous that each ſhould attain it's greateſt altitude, *the ſquares of the diameters of the conduit-pipes, muſt be to each other in the componnd ratio of the ſquares of the diameters of the ajutages, and the ſquare root of the altitude of the reſervoir.* Thus, if you know by experience the diameter that ought to be given to a conduit-

pipe,

OF PUMPS.

What I have ſaid to you concerning conduit-
pes, the efflux of water from different apertures,
c. naturally leads us to conſider the nature and action
pumps: their general principles were explained
you in my Lectures on Air. I there, however,
ly noticed two kinds: I ſhall now bring you
quainted with ſome further varieties in their
nſtruction, and notice ſome circumſtances that I
ſſed over in the former Lecture.

OF THE CHAIN-PUMP.

Among theſe is what is called the chain-pump.
is is generally made from twelve to twenty-four
et in length; conſiſts of two collateral ſquare bar-
s, and a chain of piſtons of the ſame form, fixed
proper diſtances thereon.

The chain is moved round a coarſe kind of
eel-work, fixed at one end of the machine. The
eth of this are ſo contrived as to receive one half of
e flat piſtons, and let them fold in, and they take
ld of the links as they riſe. A whole row of the
ſtons (which go free of the ſides of the barrel by
ar a quarter of an inch) are always lifting when
e pump is at work; and as this machine is gene-
ly worked with briſkneſs, they bring up a full
re of water in the pump. It is wrought either
one or two handles, according to the labour re-
ired.

The chain-pump is ſo contrived, that, by the
ntinual folding in of the piſtons, ſtones, dirt, and
atever may happen to come in the way, may
o be cleared: it is therefore uſed to drain ponds,
vers, and remove foul water, in which no other
mp could be employed.

OF PUMPS WHERE THE PRESSURE OF THE ATMOSPHERE IS EMPLOYED.

Theſe are pneumatic as well as hydraulic engines, and are uſually divided into two kinds: 1, the *common, or ſucking pump*; 2. the forcing pump. The nature of theſe, their action and operation, I ſhall explain by theſe glaſs models; in which you will ſee the motion of the piſtons, and the play of the valves.

OF THE COMMON PUMP, *fig.* 1, *pl.* 3.

I have poured water into the trough, which trough is to repreſent the well from which the water is to be raiſed. There are two valves in this pump: one (b) at the upper end of the ſmall tube; the other (a) on the moveable piſton. When the pump is not worked, their weight makes them lie cloſe upon the holes over which they are placed. I raiſe or depreſs the piſton by means of the piſton-rod.

Let us now commence our operation. The piſton being placed at the bottom of the barrel, before I begin to work, I raiſe the piſton from the bottom to the top of the barrel; which makes room for the air in the pump, below the piſton, to expand itſelf. The air in the pipe being thus dilated, preſſes leſs on the ſurface of the water within the pipe, than the atmoſphere does without on that in the trough; and conſequently the water riſes in the tube till the preſſures are equal; that is, till the air within is juſt as denſe as that without; and it will there remain at reſt between the two equal preſſures. The valve at the bottom, which roſe a to let ſome of the rarified air into the barrel, falls down again, and cloſes the hole at the top of the pipe.

I now depreſs the piſton; and as the air in the barrel cannot get back again through the valve b, at the top of the pipe, it will raiſe the valve in the piſton, and ſo make it's way through the upper part of the barrel into the open air. I raiſe the piſton again, and the air between it and the water in the lower pipe will again be left at liberty to fill a larger ſpace; and ſo it's ſpring being again weakened, the preſſure of the atmoſphere will force more water into the pipe; and when the piſton is at the top of the barrel, the lower valve falls, and ſtops the hole at the top of the pipe, as before.

The ſame effect is produced by every ſtroke, till at laſt the water in the pipe reaches the bottom of the barrel. Now upon depreſſing the piſton, as the water cannot be forced back again through the lower valve, it will raiſe the upper valve as the piſton deſcends, and will be lifted up by the piſton when raiſed again.

The whole ſpace below the piſton is now full of water; and as the water cannot eſcape by the lower valve, it will, on my depreſſing the piſton, raiſe the valve, in order to let the piſton down. When this is quite at the bottom, the valve will fall by it's weight, and ſtop the hole in the piſton. When the piſton is next raiſed, all the water above it will be lifted up, and run out of the ſpout; and thus, by alternately raiſing and depreſſing the piſton, there is ſtill more water raiſed; which, getting above the pipe into the wide part at top, will ſupply the ſpout, and make it run with a continual ſtream.

Thus you have ſeen, that every time I *elevate* the piſton, the lower valve *riſes*, and the upper valve falls; but that every time I *depreſs* the piſton, the lower valve *falls*, the upper one riſes.

Now as it is the preſſure of the air of the atmoſphere which cauſes the water to riſe, and follow the piſton, as it is drawn up; and as a column of water, of thirty-three feet high, is of equal weight with as thick a column of air, from the earth to the very top of the atmoſphere; therefore the perpendicular height of the piſton from the ſurface of the water in the well, muſt always be leſs than thirty-three feet, otherwiſe the water will never riſe above the piſton. But when the height is leſs, the preſſure of the atmoſphere will be greater than the weight of the water in the pump, and will therefore raiſe it above the piſton; and when the water has once got above the piſton, it may be thereby lifted to any height, if the rod be made long enough, and a ſufficient degree of ſtrength be employed to raiſe it with the weight of water above the piſton.

The force required to work a pump, is as the altitude of the water to be raiſed, and as the ſquare of the diameter in that part where the piſton works. Hence, if two pumps be of equal height, and one of them be twice the bore of the other, the largeſt will raiſe four times as much water as the narroweſt, and will therefore require to be worked with four times as much ſtrength.

The wideneſs or narrowneſs of the pump, in any other part, beſides that where the piſton works, does not render the pump either more or leſs difficult to work, except what difference may ariſe from the friction of the water in the bore, which is always greater in a narrow bore than a wide one.

The pump-rod is generally raiſed by means of a lever, whoſe longer arm, where the power is applied, is generally five or ſix times the length of the ſhorter arm; by which means it gives five or ſix times as much advantage to the power.

Mr. Ferguſon gives the following table for ng the dimenſions of a pump that ſhall work a given force, and draw water from a given h, the handle being ſuppoſed to increaſe the r five times. It is alſo ſuppoſed that one man work a pump four inches diameter, and thirty high, and diſcharge 27½ gallons of water in a te; the meaſure being that called Engliſh -meaſure.

Height of the pumps above the ſurface of the well.	Diameter of the bore where the piſton works.	Water diſcharged in a minute.	
Feet.	*Inches.*	*Galls.*	*Pts.*
10	6.93	81	6
15	5.66	54	4
20	4.90	40	7
25	4.38	32	6
30	4.00	27	2
35	3.70	23	3
40	3.46	20	3
45	3.27	18	1
50	3.10	16	3
55	2.95	14	7
60	2.84	13	5
65	2.72	12	4
70	2.62	11	5
75	2.53	10	7
80	2.45	10	2
85	2.38	9	5
90	2.31	9	1
95	2.25	8	5
100	2.19	8	1

Now, to find the diameter of a pump that ſhall raiſe water with the ſame eaſe as a man can work a pump thirty feet high, with a four-inch bore, look for the height in the firſt column, and over againſt it, in the ſecond, you have the diameter or width of the pump, and in the third you find the quantity of water which a man of ordinary ſtrength can diſcharge in a minute.

OF THE FORCING PUMP, *fig.* 2, *pl.* 3.

It is ſo called, becauſe it not only raiſes the water into the barrel, like the foregoing, but it afterwards forces it up into a reſervoir, in a lofty ſituation. The operation and nature of this pump will be evident by attending to the working of this model, *fig.* 2, *pl.* 3. The pipe and barrel are the ſame as in the other pump, but the piſton, G, is ſolid, having no valve, ſo that no water can get above it. At the bottom of the barrel B a pipe M M is fixed, and at right-angles to this pipe a ciſtern, or air-veſſel, KK; at the bottom of the air-veſſel there is a valve, b; from the top a ſmall pipe, O H I, is inſerted ſo as nearly to reach the bottom of the air-veſſel, and at the ſame time be air-tight at top.

I ſhall now begin to work the model, that you may ſee and comprehend the effects. The pipe-valve, a, riſes when I draw the piſton up; but falls down, and ſtops the hole, the moment the piſton is at it's greateſt height. Now as the water which has been raiſed above this valve cannot get back again into the pipe, but has a free paſſage by the pipe M M, that opens into the air-veſſel, it is forced into this veſſel by depreſſing the piſton, and retained therein by it's valve b; which ſhuts the moment the piſton begins to be raiſed, becauſe the preſſure of the water againſt the under ſide thereof then ceaſes.

The water being thus forced into the air-veſſel by repeated ſtrokes of the piſton, has now got above the lower end, I, of the pipe, and begins to condenſe the air in the air-veſſel; for the air has no way to get out of this veſſel, but through the tube O H I of the pipe, and is prevented from eſcaping this way when the mouth of this tube is covered with water. It is alſo gradually more and more condenſed as the water riſes in this veſſel; till at laſt, as you ſee, it preſſes ſo ſtrongly upon the water as to force it up through the pipe O H I; from whence it ſpouts at F in a jet to a great height, and is ſupplied by alternately raiſing and depreſſing of the piſton.

The higher the ſurface of the water is raiſed in the air-veſſel, the ſmaller is the ſpace into which the air is condenſed; and conſequently it's ſpring will be ſtronger, and the preſſure greater upon the water, which will be thereby driven with greater force through the pipe; and as the ſpring of the air continues to act even while the piſton is riſing, the ſtream will be uniform as long as the piſton is worked.

The valve of the pipe opens to let the water follow the piſton in riſing. Whilſt this valve is open, that of the air-veſſel is cloſed, to prevent the water, which is forced into the air-veſſel, from running back by it's pipe into the air-veſſel.

The effect of this kind of pump is not limited to raiſing water to any particular altitude; ſince the air's condenſation may be raiſed to any degree.

If the air's condenſation is double to that of the atmoſphere, it's elaſtic force will raiſe the water to about the height of thirty-four feet. If the condenſation be increaſed three-fold, the altitude to which water may be raiſed by it will be about twice the former height, or ſixty-eight feet; the altitude of the raiſed water being increaſed thirty-four feet for each addition of unity to the number which expreſſes the air's condenſation.

The engines uſed for *extinguiſhing fire* are upon this conſtruction; conſiſting of 2 barrels, by which water is alternately driven into a cloſe air-veſſel. The forcing the water therein condenſes the air, which compreſſes the water ſo ſtrongly, that it ruſhes out with great impetuoſity and force through a pipe that comes down into it, and makes a continued uniform ſtream by the condenſation of air upon it's ſurface.

OF DE LA HIRE'S PUMP, *fig*. 3, *pl*. 3.

The model before you is that of a pump invented by *M. De la Hire, which is ſo conſtructed, as to raiſe water as faſt by the deſcent as the aſcent of the piſton.* As before, the trough in which the two pipes are placed repreſents the well: one of the pipes, B, is fitted to the lower end of the barrel in which the piſton works; the top of the other pipe, C, is ſo connected with a ſmaller one, as to communicate with the upper part of the barrel. There is a valve on the top of the pipes B, C, and alſo on the two pipes E F, which proceed from the pump-barrel into the air-veſſel P. The piſton is ſolid, or without any valve or opening.

As the piſton riſes, the air, preſſing on the ſurface of the water in the trough, forces it up the pipe B, at the bottom of the barrel, and fills it with water up to the piſton. The valves e and s lie cloſe and air-tight at the top of their reſpective pipes E and F.

When the piſton ſtops at it's greateſt height, the valve at the bottom of the barrel cloſes, and prevents the water from being forced back. Hence, as the piſton is depreſſed, it forces all the water in the barrel up through the lower crooked pipe F, and through it's valve, into the air-veſſel.

The piſton-rod moves through what is called a collar of leather, which makes it air-tight.

During the deſcent of the piſton, the valve upon the upper crooked pipe falls down, and the preſſure of the air on the water in the trough raiſes the water through this pipe, C, and the valve at the top of it, which is opened upwards by the power of the aſcending water; and this water runs into the barrel of the pump, and fills all the ſpace therein above the piſton.

As ſoon as the piſton is as low as it can go, the valve at the end of the upper pipe, D, falls down and cloſes it, ſo that no water can be forced back through it. As the piſton is raiſed, all this water is forced through the upper pipe E, and, after opening it's valve e, into the air-veſſel P.

Thus, as the piſton deſcends, it forces all the water below it up the pipe F; and, as it riſes, it forces all the water above it up the pipe E; ſo that there is as much water forced up into the air-veſſel by the aſcent, as by the deſcent of the piſton. The air is compreſſed in the air-veſſel as in the preceding caſe; and the water being equally forced in, ruſhes out with a conſtant and very nearly equal ſtream. It is evident, from what we have already told you, that the top of the pipe that opens into the upper part of the barrel ſhould never exceed thirty-two feet.

OF A NEW HAND-PUMP, INVENTED BY MR. WALTER TAYLOR, OF SOUTHAMPTON, AND USED BY THE ROYAL NAVY OF GREAT BRITAIN.

Every friend of mankind muſt rejoice on being informed, that the accidents to which ſhips that ſpring a leak at ſea were liable from the imperfections of the chain-pump, are happily removed by the ingenious contrivances of Mr. *Walter Taylor*, of Southampton, well known for his mechanical abilities; which in other inſtances, as well as this, have proved equally beneficial to himſelf and his country. It ſeems rather ſurprizing that the common pump, whoſe effects are ſo well known, ſhould have remained for centuries inadequate to the purpoſes of the navy. The mechaniſm adapted by Mr. Taylor is ſo important, and, in various particulars, ſo different from what is in general applied to the common pump, that it may with great propriety be conſidered as a new invention.

Mr. Taylor's pumps have been in general uſe in the royal navy for five or ſix years: they have anſwered every expectation he firſt formed, though he has made many improvements on them during that period. Here are three figures, which will give you a general idea of theſe pumps; they were copied from drawings which were kindly communicated to me for this purpoſe by Mr. Taylor. *Fig.* 4, *pl.* 3, is a ſection of one of Mr. Taylor's pumps, of a ſimple conſtruction. The piſton is repreſented as deſcending in a chamber properly adapted thereto. At a and b you have a view of Mr. Taylor's pendulum valves; which, from their form, diſengage themſelves from chips, gravel, ſand, &c. The piſton is alſo ſo contrived, that no chips, gravel, or ſand, can get between the leather and lower part of the piſton; to both which defects the former conſtructions were liable. *Fig.* 7 is a ſeparate view of the pendulum valve.

Fig. 3 repreſents a pump working with one piſton-rod, and *fig.* 5 a pump working with two piſton-rods; the one riſing as the other falls: in *fig.* 4 and 5 the rods are ſuppoſed to be worked by levers. By a judicious application of ropes, to be carried on either deck, (ſee *fig.* 6,) Mr. Taylor is enabled, where men are plenty, as in a man of war, to raiſe any quantity of water. The drawing is taken from a pump with a ſeven-inch bore, and heaves one ton per minute twenty-four feet high, with ten men, five only working at a time. One is now conſtructing by Mr. Taylor to heave five tons per minute twenty-four feet high. The pumps are alſo ſo conſtructed that a copper pump may be taken out of the wooden caſe, in order, when neceſſity requires, to make two pumps for ſeparate work.

OF THE HESSIAN PUMP, *fig.* 7 *and* 8, *pl.* 2.

ABC, DE, two tin veſſels, ſoldered together, but communicating with each other by a hole at bottom. The larger veſſel is furniſhed with a rim, to receive the water thrown up by the circulating tubes, and convey it into the veſſel DE. m, n, o, p, repreſent four tubes of metal, or glaſs, open at both ends, but bent at top, and fixed in an angular poſition to the axis K L. When in their place, the extremity L of the axis reſts upon a point at the bottom of the large veſſel, while the upper part is ſteadied, and kept in a vertical poſition, by paſſing through a hole in a bar going over the large veſſel A B C.

Fill the veſſels about two-thirds with water, and then make the tubes circulate rapidly by turning the handle S, and the rotatory centrifugal motion will raiſe the water, and diſcharge it into the ſmall veſſel D E, by the pipe h.

OF VERA'S PUMP, fig. 8, pl. 3; OR AN ENGINE TO RAISE WATER BY MEANS OF HAIR ROPES.

A and B are three hair ropes paſſing over the pullies b and d, each of which has three grooves. The lower pulley, b, is immerſed in the water, and is kept therein by a weight ſuſpended from it. Theſe pullies are turned round with great rapidity by means of two multiplying wheels, one of which is ſeen at G. By turning the pullies, the cords revolve alſo with great rapidity, and the aſcending ſides carry up a conſiderable quantity of water, which they diſcharge with violence into the reſervoir H, from whence it is conveyed into any convenient place by the pipe K L. The ropes ſhould not be more than an inch aſunder.

There are two of theſe machines at Winds. The depth of the well where one of them is fixed is ninety-five feet, and the quantity of water raiſed by the utmoſt efforts of a man is about nine gallons per minute.

In the beginning of the motion, the column adhering to the rope is always leſs than when it has been worked for ſome time, and continues to increaſe till the ſurrounding air partakes of it's motion.

OF A SUPPOSED IMPROVEMENT OF THE COMMON PUMP.

In the year 1766 it was announced in the public papers, that at Seville, in Spain, a ſimple ſucking pump had been conſtructed, *which raiſed water ſixty feet;* and they concluded from thence, that thoſe were ſtrangely deceived who had aſſerted that the preſſure of the atmoſphere would not ſupport a higher column than thirty-two feet. On examination it was found, that an ignorant tinman at Seville had made a common ſucking pipe with it's lower valve ſixty feet from the ſurface of the water; but finding he could raiſe no water by it, either through impatience or paſſion, with a ſtroke of a hatchet he made a ſmall opening about ten feet above the ſurface of the water, and which forced a ſmall quantity of water above the lower valve; the reaſon of which I ſhall explain by a diagram.

Let P F, *fig.* 1, *pl.* 3, be the ſucking tube, d the ſurface of the water, from d to F ſixty feet; and that after a certain number of ſtrokes of the piſton the water was raiſed thirty-two feet in the tube, or to *c;* and that then a ſmall hole was made at ten feet from the ſurface of the water. The air which enters this preſſing equally every way, makes the water which is below *b* fall down into the well; while the preſſure upwards forces the water up thirty-two feet, through the valve, into the body of the pump. But this is not all, for it would have carried it to a much greater height; for the air near the earth is above eight hundred times rarer, or leſs denſe, than water; and ſuppoſing the denſity of a column thereof to be uniform (which is not the caſe), ten feet of water taken away would be equivalent to a column of eight thouſand feet of air; ſo that the remaining twenty-two feet would be in equilibrium with the air, after being raiſed eight thouſand feet. To have a ſecond portion of water, the hole *b* muſt be ſtopped up, and the piſton worked till the water riſes to c, and then re-open the hole. In the firſt place you ſee, that this pretended diſcovery is ſo far from invalidating the principle of the preſſure of the air, that it is a direct conſequence thereof; ſecondly, that even to make it anſwer at all, it is neceſſary that the pipe be very ſmall, or the column of water would be broke to pieces, the air would paſs through, and very little would riſe.

OF THE MOTION OF WATER IN CONDUIT-PIPES.

In conducting of water from one place to another, the conduit-pipes muſt be longer in proportion as the places to which it is to be conveyed are more diſtant from each other. In the additional tubes heretofore ſpoken of, I took no notice of friction, as in the caſes then under conſideration it was ſcarcely ſenſible. In long tubes it is different; the friction of theſe leſſens conſiderably the velocity of the water.

On this head I can only relate to you the reſult of various experiments that have been made; which it is impoſſible for us to repeat, as they require not only a very large apparatus, but conveniences that are only to be procured by thoſe whoſe intereſt is concerned in the experiments. The experiments of which I ſhall give you the reſults were made by Mr. Boſſut; the tubes were ſtrait; one of them was ſixteen lines inſide diameter, the other two inches; and the tubes were ſucceſſively lengthened from thirty to an hundred and eighty feet. The conſtant altitude of the water in the reſervoir,

ove the axis of each tube, was in ſome caſes one
ot, in other caſes two feet. This is a branch of
ydroſtatics, in which theory is neceſſarily imper-
ct, and the only means of arriving at truth muſt
from experiment.

Conſtant altitude of the water in the reſervoir above the axis of the tube, expreſſed in ft.	Diſtance to which the water was conveyed, expreſſed in ft.	No. of cubic inches of water diſcharged by the tube of 16 lines diameter in a minute.	No. of cubic inches of water diſcharged by the tube of two inches diameter in a minute.
1	30	2778	7680
1	60	1957	5564
1	90	1587	4534
1	120	1351	3944
1	150	1178	3486
1	180	1052	3119
2	30	4066	11219
2	60	2888	8190
2	90	2352	6812
2	120	2011	5885
2	150	1762	5232
2	180	1583	4710

By comparing this with the table in page 478,
u will find that the diſcharges of water there are
uch greater than the correſponding ones in the
eſent table, and that the diſcharge is leſſened as
e tube is lengthened, becauſe there is a greater
bbing ſurface.

We may alſo notice that the diminution in the
ſcharge is not in proportion to the length of the
be; for the firſt thirty feet diminiſhes the diſ-
arge much more than the ſecond thirty feet, and
e third length of thirty feet diminiſhes ſtill leſs
the diſcharge, and ſo on.

From these experiments it appears, that great accuracy is not neceſſary in practice; and perhaps we may adopt, for a general rule, *that the diſcharge made in equal times by an horizontal tube, with the ſame altitude of the water, but at different diſtances from the aperture of the tubes, are to each other very nearly in the inverſe ratio of the ſquare roots of the lengths.*

The diſcharge is more in proportion from the larger tube than from the ſmaller one; becauſe there is leſs rubbing ſurface in proportion in the larger tube.

If the tubes are curved, inſtead of being ſtrait, the diſcharge will be ſomewhat diminiſhed. This diminution in the diſcharge appears to ariſe from the impact of the water againſt the angular points of the tube, whereby it's velocity is diminiſhed. This diminution will therefore vary with the number of the curvatures.

When the plane of the curvature of the tube is in a vertical direction, there will be portions of the tube where the air will fix itſelf, ſo as to leſſen the velocity, or even ſtop the courſe of the water. Let A B C D E, [illegible], be a tube, whoſe upper end A is joined to the reſervoir that furniſhes the water, G the end by which the fountain is ſupplied. When the communication at A is opened, the tube is [illegible] the water will fill the tube A B, drive out the air therefrom, and riſe to C. Here [illegible], and the water runs down the lower part of the curvature, and fills up the [illegible] D, leaving behind it the column of air C D; which will remain there, notwithſtanding the preſſure of the column of water A B. The water continuing its way, runs down the lower part of E F, and [illegible] r, leaving the ſecond column of air [illegible] that the water will be only raiſed to I, and will not run out at G.

OF THE SYPHON.

Though I treated of the ſyphon in an early ſtage of theſe Lectures,* as the account there given does not ſeem ſo correct as that given by a late author,† I ſhall here endeavour to ſtate with greater accuracy the principle on which it acts.

A *ſyphon* is an inſtrument uſed to decant fluids, or convey them from one place, over an obſtacle that is higher than their ſurface, to another that is lower. It's form, as you have ſeen, is exceeding ſimple, being nothing more than a crooked tube. It's effects are accounted for from the gravitation of fluids of different weights, one upon another.

If one leg of a ſyphon be immerſed in a veſſel of water, and the other leg hang out of it, in ſuch manner that the lower end be below the ſurface of the water, on opening both the orifices at the ſame inſtant, the water will be found to flow out at the lower orifice, till it's ſurface has ſunk down to the orifice of the leg in the water.

Now, on examining this experiment, you will find, that the columns of air preſſing on the two equal orifices, differ from each other in length only by the *perpendicular diſtance between the ſurface of the water, and the horizontal plane of the lower orifice of the ſyphon;* which ſpace, compared with the whole height of the atmoſphere, is too inconſiderable to be taken into the account; and we may therefore conclude, that the action of the atmoſphere on both the orifices is *equal.*

Now as we ſuppoſed the tubes full of water when the holes are firſt opened, theſe *equal* preſſures of the atmoſphere will be counteracted by the

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* Lecture iii. vol. i. p. 94.

† Theory of the Syphon. London, 1781.

the weight of two *different* columns of water; one in the ſhorter, the other in the longer leg of the ſyphon. The difference of the force of theſe counteracting preſſures, is equal to the weight of a column of water whoſe baſe is equal to the diameter of the tube, and whoſe height is equal to the perpendicular height of the ſurface of the water from the orifice of the longer leg. Now *equal** preſſures of the atmoſphere will be counteracted by *unequal* forces of gravitating waters, which will make the oppoſite preſſures of the vertex unequal: and as the ſuperior weight of the longer column carries it downwards, there is leſs preſſure on that ſide of the vertex; the water will be preſſed forwards, and continue to flow, till the water be fallen to the bottom of the immerſed leg, or (if it be the longer leg) as low as the end of the flowing one; for the deſcent of the water in the longer leg, by it's own gravity, would leave a vacuum in the tube, if not immediately ſucceeded by other water. This deſcent gives the atmoſphere, which urges the water up the ſyphon, the ſame power to act as if it were not *at all* oppoſed at the iſſuing orifice.

For the ſame reaſon that the atmoſphere urges the water in the veſſel *after* that which deſcends, it would *fill the whole* ſyphon, provided it were void of air; and by ſucking the air out of the ſmaller kind of theſe inſtruments with the mouth, through a pipe placed for that purpoſe by the ſide of the iſſuing leg, they are eaſily ſet a running. In larger ſyphons, for the draining of pits, quarries, &c. the evacuation is effected by a pump placed in like manner at the iſſuing end.

Of the Diſtillers' Syphon. This is uſually about an inch in diameter, and three feet in length, with a cock fixed into the iſſuing end. To uſe it, the cock is ſhut, and the contrary end is put into the bung-hole, till the liquor reach within about five or ſix inches of the bend. Then, on opening the cock pretty quickly, the contents flow out of the ſyphon in the uſual manner. By the immerſion of the drawing leg, the liquor is prevented by the pent-up air from riſing as high *within* the ſyphon as it is on the outſide thereof. On opening the cock, the ambient fluid obtains power to raiſe that within the tube to it's own level; but, by a law already explained, the contained liquor, before it riſes as high as that of the other, will have acquired a velocity nearly ſufficient to carry it as much above that ſurface as it was before below it. Hence the fluid ſhoots over the bend; and there falling into a tube with a contracted orifice, the ſyphon is ſoon filled, and of courſe continues to flow as in the common experiment.

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* For if you ſuppoſe the atmoſphere more than able to ſuſtain the water in each leg, it will at the firſt inſtant of opening the orifices, preſs their reſpective contents againſt each other at the vertex.

s'Graveſande's Syphon. This is a ſyphon for raiſing water into a ciſtern by means of the expenditure of other water through the outer leg, and may be applied to many caſes where water, &c. is to be raiſed ten or twenty feet, and where you have at the ſame time water ſufficient to ſupply the lower reſervoir. This ſyphon has been lately much improved by a very ingenious gentleman.*

OF THE VIBRATORY MOTION OF WATER IN A SYPHON.

I have proved to you, in the Lectures on Mechanics, that the vibrations of a pendulum are iſochrone

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* s'Graveſande's Elements of Philoſophy, vol. i. p. 235.

iſochrone, or of the ſame duration, though the arches it deſcribes are unequal. I have alſo ſhewn you, the duration of the vibrations of two unequal pendulums are to each other as the ſquare root of their reſpective lengths. The motion of water vibrating in a ſyphon follows the ſame laws.

To illuſtrate this, let us ſuppoſe *l, o o m*, to be a ſyphon conſiſting of three parts, or legs; two, *l n*, *m o*, vertical, and one, *n o*, horizontal; and that it be of an equal diameter throughout it's whole extent. Let us further ſuppoſe, that the fluid, while at reſt, occupies the ſpace *a n o d*, the two ſurfaces, *a b*, *c d*, will be level. Now if by any means the fluid be forced to deſcend to *g b* in the leg *n o*, it will riſe to *e f* in the leg *l n*; and as ſoon as this cauſe ceaſes to act, the fluid is left alone to the action of it's gravity. The exceſs in length of the column *e n* over the column *b o*, will force the fluid to deſcend even below the level of the other, on account of the acceleration it acquires in deſcending, which will raiſe the fluid in the other leg; and it will thus continue riſing and falling alternately, forming oſcillations ſimilar to thoſe of a pendulum; and the duration of each vibration will be preciſely the ſame as the vibration of a pendulum, whoſe length is half the length of the column *p q r* of the fluid.

As the oſcillations of water follow the ſame laws as thoſe of a pendulum, if the length of the column of water is increaſed or diminiſhed, the duration of the oſcillations will be alſo augmented and diminiſhed, and will be in a ſubduplicate ratio of this length.

OSCILLATORY MOTION OF WAVES.

Newton, in his Principia, compares the undulatory motion of waves, to the vibratory one of in a ſyphon. Let ABCDEF, *fig.* 10, *pl.* 2, repreſent a ſtagnant water, whoſe ſurface is elevated and depreſſed by ſucceſſive waves. Let A, C, E, be the convex, and B, D, F, the concave part of the waves. As waves are formed by the ſucceſſive aſcent and deſcent of the water, ſo that thoſe parts which were the higheſt become the loweſt alternately and ſucceſſively; and as the moving force which makes the loweſt parts riſe, and the higheſt ſink, is the weight of the elevated water, this aſcent and deſcent may be conſidered as analogous to the vibratory motion of water in a ſyphon, and obſerves the ſame laws.

If, therefore, you have a pendulum, whoſe length be equal to half the tranſverſal diſtance between the moſt convex point A, and the moſt concave point B, that is, equal to the half of A b; the higheſt part will become the loweſt during the vibration of ſuch a pendulum, and in another vibration they will become the higheſt, going through it's whole ſpace while the pendulum performs two vibrations. And as a pendulum whoſe length is quadruple the preceding one, that is, which is equal to the width A C of the waves, would perform but one vibration while the other performed two, we conclude that the waves perform their vibrations in the ſame time as a pendulum, whoſe length is equal to the breadth of the waves.

From hence it follows, that a wave, whoſe breadth is 3 feet $8\frac{17}{30}$ lines broad, by advancing it's whole breadth in one ſecond, would in a minute deſcribe 183 feet 6 inches 10 lines; and in an hour, 11014 feet 2 inches.* If the breadth was quadruple, it would deſcribe the breadth in double the time; conſequently the broader they are, the greater ſpace they deſcribe in a given time.

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* By the breadth of a wave, we mean the tranſverſe ſpace A C, which is between the two greateſt elevations, or that B D, between the utmoſt depreſſions.

In the foregoing reaſoning, I have aſſumed that the waves roſe and fell in ſtrait lines; but this is not exactly true, and conſequently the deductions can only be conſidered as approximations towards the truth.

OF THE RESISTANCE OF FLUIDS.

One of the moſt important problems in hydroſtatics, is to determine the reſiſtance that a body in motion meets from a fluid at reſt; and to know the effort neceſſary to keep a body at reſt in a fluid in motion.

Water and air are two of the great inanimate agents in nature, and they are thoſe which man renders moſt eaſily ſubſervient to his purpoſes. Neceſſity firſt pointed out the uſe of theſe agents, and engaged him to inveſtigate their properties. In this reſpect, however, much of his labour has been ſpent in vain; particularly that which has been employed in the reſolution of the above-mentioned problems. Theſe have hitherto evaded every reſearch, though they have engaged the attention, and exerciſed the talents, of the greateſt mathematicians.

I have ſhewn you, by many inſtances, that the philoſophy of the *ancients* was neither ſo unreaſonable, nor ſo limited, as it has often been repreſented. It does not, however, appear, that they were well verſed in the ſcience that is termed *mixed mathematics*, or mathematical philoſophy; a ſcience which conſiſts in the application of calculation to the phenomena of nature. Among the branches of this ſcience which they have the leaſt ſtudied, we may reckon that of the reſiſtance of fluids; for we muſt confeſs, that they had obtained ſome knowledge thereof, as it was neceſſary for the conſtruction of their ſhips, the principles of building which they had carried further than the moderns.

Modern mathematicians have imagined themſelves reſiſtance of the fluid; much here will, however, depend on the form, magnitude, &c. of the moving body, and the velocity of it's motion; for a greater body will diſplace a greater quantity of the fluid than a ſmaller one, every thing elſe being the ſame; and the greater the velocity wherewith a body moves in a fluid, the more motion will be communicated thereto, and conſequently loſt to the body.

There is another cauſe of reſiſtance which ariſes from the tenacity of the parts of a fluid; for as a body cannot move forward in a fluid till the parts that lie before it are removed out of the way, the adheſion or tenacity muſt neceſſarily reſiſt it's motion.

There is a third cauſe of reſiſtance, that is, the friction of the body againſt the particles of a fluid; but this, from the nature of fluids, is deemed to be very inconſiderable.

The reſiſtance will alſo depend on the fluid's denſity, every thing elſe being the ſame; for it is manifeſt, that it will require more force to diſplace a given quantity of mercury than the ſame quantity of water, and a quantity of water than an equal quantity of air.

But the principal reſiſtance which fluids give to bodies in motion, is ſuppoſed to ariſe from the inertia of their parts, and this depends on the *velocity of the moving body*, and that for two reaſons. In the firſt place, the quantity of fluid moved out of it's place, in any determinate ſpace of time, muſt be greater in proportion as the body moves with greater velocity through the fluid. And, in the next place, the velocity with which each particle of the fluid is moved, will alſo be proportional to the velocity of the body; for it communicates a greater or leſs quantity of motion to each particle in proportion to the velocity of it's motion, and will therefore be reſiſted on this account alſo in the proportion of the velocity. Since the reſiſtance which any body makes againſt being put in motion, is proportional both to the quantity of matter moved, and the velocity it is moved with; but as the reſiſtance of a fluid is as the velocity of the body moving therein, it will be doubly increaſed, 1. Becauſe the number of particles moved is as the velocity of the moving body. 2. Becauſe the reſiſtance ariſing from a given number of particles is alſo as the velocity of the moving body. Therefore the reſiſtance is conſidered as being in a duplicate proportion of the velocity of a moving body, or as the ſquare thereof.

A cylinder moving in a fluid, in the direction of it's axis, is reſiſted by a force equal to the weight of a column of a fluid, the baſe of which is the baſe of the cylinder, and altitude equal to the ſpace through which a body muſt fall freely from reſt to acquire the velocity of the cylinder's motion.

A ſphere moving in a fluid is oppoſed by a reſiſtance, which is to the force which reſiſts a cylinder moving in the direction of it's axis with the ſame velocity, in the proportion of 1 to 2.

Two ſuppoſitions are generally taken for granted, in proving the propoſitions on the reſiſtance of fluids: 1. That the fluid in which the body moves is ſo compreſſed, that it's preſſure on every part of the moving bodies ſhall be the ſame as when they are at reſt. 2. That the hinder part of the ſolids contribute nothing to the reſiſtance, which will be the ſame as if the anterior part only were expoſed to the fluid. This laſt ſuppoſition is not admiſſible, for the hinder part of moſt ſolids contribute to leſſen the reſiſtance by the power it receives from the returning curves of the fluid.

The theory of reſiſtances oppoſed to bodies moving in perfect fluids, could not even be demonſtrated by Sir I. Newton but under certain conditions and reſtrictions.

1. The particles of fluid wherein the bodies move are ſuppoſed to be perfectly non-elaſtic.

2. The fluid is imagined to be infinitely compreſſed.

The ſecond condition is allowed not to obtain in any fluid whatſoever, and it is doubted whether the firſt is ſtrictly applicable even to the moſt perfect known fluids.

It is certain that the reſiſtance of fluids depends on the coheſion, tenacity, and friction, as well as the inertia of the matter moved; but the illuſtrious author of the theory, here ſlightly touched upon, conſidered the geometrical eſtimation of theſe circumſtances as of no uſe in phyſical inquiries. He therefore chiefly noticed the properties of retardation, which bodies ſuffer when moving through fluids, the coheſion and friction among whoſe parts were in a phyſical ſenſe evaneſcent.

The Lectures on hydroſtatics, &c. like every other part of philoſophy, ſerve to ſhew you the weakneſs and imperfection of human knowledge, and how ignorant we are of thoſe ſubjects in which we are deeply intereſted, and with which we are continually engaged; they alſo ſhew us how long human ingenuity may be exerciſed, without improving the ſcience on which it is exerciſed. In every other part of natural ſcience new diſcoveries are made, and new phenomena are brought to view, which enlarge the boundaries of knowledge, though they convince us of greater objects and numerous phenomena that remain concealed from our obſervation; but in hydroſtatics and hydraulics, little that is new has been diſcovered, and a general ſhade of ignorance ſeems to be caſt over the whole ſcience.

The Lectures on hydroſtatics and hydraulics clearly ſhew, that thoſe modern philoſophers err much, " who, in zeal for the honour and perfection of their favourite ſtudy, contend that almoſt every thing in phyſics is demonſtrable; not conſidering how far a mathematical concluſion will extend, and how far not; and forgetting that *hypothetical forces* will afford them as much matter to work on, as thoſe that are real.

" To make a ſatisfactory progreſs in natural philoſophy, you ſhould be very attentive to the *nature* of phyſical *truth*. Experiments, which are the baſis and ſupport of all ſound philoſophy, though choſen with propriety, and made with the utmoſt accuracy, are incapable of penetrating into the *real* eſſences of things. They can only inform the ſenſes of ſome of the *apparent* qualities of bodies, and enable us to inveſtigate ſome of the ſecondary or phyſical cauſes; and ſometimes they do not reach ſo far, and we learn nothing but the bare phenomena or effects."

Man has before him all nature, the whole world with which he is ſurrounded for the object of his view, and the ſubject of his conſideration; but his capacity is ſo circumſcribed, his knowledge ſo ſtraightened, his powers ſo limited, that he can by no means conceive the mechaniſm of ſo vaſt and complicate a ſtructure. No experiments can ſhew him the internal frame of any one part; the component elements thereof eſcape his ſight through their minuteneſs; the heavenly bodies, be they ever ſo large, are too remote for his introſpection.

So that our views of nature are like the *map* of an inland country, where you ſee rivers without any ſources continually diſcharging their waters without a ſea to receive them; roads that you know not whence they come, nor whither they go; mountains, foreſts, and plains, cut off in the middle by the marginal lines of the paper: but even of thoſe things which we know well, there is much that ſurpaſſes the extent of our faculties. We know the ſun ſtands ſtill, and that the earth rolls round him with inconceivable rapidity; yet to think of the ſtately fabrics, the ſpacious cities, the ſeated mountains, the brimming ocean, and the univerſal quieſcence of a ſtill evening ruſhing forward with ſuch inceſſant impetuoſity, is an idea too unwieldy for our imagination; we know fire only diſſipates but does not deſtroy, yet we currently talk of it's drying up, conſuming, and deſtroying. We know matter to be inert and ſenſeleſs, and yet we aſcribe force to ſtorms and inundations; activity to ſpirituous liquors, and drugs; inclemency to ſeaſons; kindlineſs to dews; benignity to vernal gleams; giving bodies theſe and other powers belonging to ourſelves. Thus, whereever we turn our view, we find in ſcience no reaſon for boaſting, no foundation for pride.

This *viſible* world, in which we are placed, when carefully viewed and examined by the enlightened powers of the human underſtanding, proclaims, indeed, the power, wiſdom, and mercy of the eternal Godhead. His *inviſible* glories are ſomewhat repreſented to us by the things that are ſeen; the *ſun* beaming forth light and life to our ſyſtem, proclaims in language known to all his Maker's ſacred glory, whoſe power ſupplies the never-failing fountain with it's endleſs heat and light. When we conſider the great and wide ocean as carried orderly round in it's daily revolutions, how are we aſtoniſhed at the power that guides the tremendous maſs? How mighty are the words that ſay, "Thus far ſhalt thou go and no farther?" How powerful the arm that keeps within bounds it's tumultuous workings, and that directs it in the beautiful regularity of it's courſe?

Who can refrain from falling down with reverential ſilence, when he conſiders the magnificent ſtructure of the univerſe? Yet how ſmall a part of the great things around us can be taken in by our limited faculties? We ſee enough to ſurpriſe us, the great *viſible* effects proclaim the majeſty of the *inviſible* cauſe; further than this they *do* not, they *can* not go.

No other *eye* than the DIVINE is equal to the view of nature; and no *mind* leſs than that of the GREAT DESIGNER is able to perceive, with perfect clearneſs, the uniformity of the deſign amidſt the vaſt variety of parts that are to outward appearance ſo diſſimilar and heterogeneous. There is nothing in which the nature of man prides itſelf ſo much as in ſuperior knowledge and wiſdom; and yet how low is the point to which human knowledge can aſcend! In the objects which ſurround us, in ſubjects in which we are moſt nearly intereſted, how ſmall is the part we can diſcover! The beſt directed and moſt ſucceſsful reſearches only inform us how little is known, and give us no cauſe to be ſatisfied with the diſcoveries they have made.

LECTURE XXXVI.

On Astronomy.

HE heavens declare the glory of God, and
the firmament ſheweth his handy work.

In them hath he ſet a tabernacle for the ſun,
ich is as a bridegroom coming out of his cham-
r, and rejoiceth as a ſtrong man to run a race.

His going forth is from the end of heaven,
d his circuit unto the ends of it, and there is
thing hid from the heat thereof.

When I conſider the heavens, the work of thy
gers, the moon and the ſtars which thou haſt or-
ined, what is man, that thou art mindful of him?
the ſon of man, that thou viſiteſt him?

Praiſe ye him ſun and moon, praiſe him all ye
rs of light.

Let them praiſe the name of the Lord, for he
nmanded and they were created.

O Lord, how manifold are thy works! in
ſdom thou haſt made them all.

Tranſported with a ſurvey of the wonders
ich preſent themſelves in heaven above, and on
th below, the Royal Pſalmiſt breaks forth into
exclamation on the variety and grandeur, the
rmony and proportion of the works of God.
e is ſtruck with the awful magnificence of the
de extended firmament, where the *ſun*, that foun-
n of life, and heart of the world, that bright
der of the armies of heaven, is enthroned in
rious majeſty; where the *moon* ſhines with a
tre borrowed from his beams, amidſt a multi-

tude of ſhining orbs differing from each other in magnitude and ſplendor. Theſe, though they have neither ſpeech nor language, yet by their ſplendor and magnificence, their motions and their influences, all regulated and exerted according to the ordinance of their maker, do in a very intelligible and ſtriking mannner declare the GLORY of GOD,* and are magnificent heralds of their maker's praiſe.

To contemplate theſe ſublime and intereſting objects, and to explain to you the phenomena which ſo eminently ſignalize the celeſtial worlds, is the buſineſs of the Lectures on Aſtronomy. Of the various branches of ſcience cultivated by mankind, *aſtronomy* is one of the moſt important and moſt uſeful; our faculties are enlarged by the grand ideas it conveys, and the mind is exalted above the contracted prejudices of the vulgar and illiterate. It explains to you the laws or rules that govern and direct the motions of the heavenly hoſt, and by which the ALMIGHTY carries on and continues the wonderful harmony, order, and connection, obſervable throughout the planetary ſyſtem; it enables us to diſcover the ſize of the planets, and determine their reſpective diſtances. By the knowledge derived from this ſcience, we diſcover alſo the bulk of the earth, and aſcertain the ſituation and extent of the countries and kingdoms into which it is divided; by aiding the navigator, and facilitating his paſſage through the trackleſs ocean, trade and commerce are carried on to the remoteſt parts of the world, and the various products of the ſeveral countries are diſtributed for the health, comfort, and convenience of it's different inhabitants.

There can be little or no occaſion to excite your

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* See Biſhop Horne's more than excellent Commentary on the Pſalms.

our attention to the wonders continually exhibited n the heavens; the magnificent objects you there iſcover, forcibly awaken the idea of their AUTHOR, y preſenting the moſt ſtriking inſtances of his ower and his glory. It is towards heaven you urn your eyes, when you look up for aſſiſtance to hat infinite goodneſs and power, from whom alone t can be received. No one, indeed, can view he immenſe expanſe of heaven, without being truck with admiration at the variety of bodies aparently in motion, with which that expanſe is dorned; at the uniformity and regularity with hich they ſeem to move from one part of the eavens to the other, always keeping within a cerain limit, and pointing out by their different ſituaions the different ſeaſons of the year, and diffuſing he various degrees of heat and light neceſſary for he preſervation of animal and vegetable life.

GENERAL PRINCIPLES OF ASTRONOMY.

Of the various phenomena that offer themelves for your obſervation, the moſt obvious is the IURNAL MOTION, or that which ſeems to be comnon to the whole heavens, and which is comleted in twenty-four hours.

Of the moving bodies, the *ſun* is the firſt that ngages our attention, not only on account of his lmoſt infinite ſuperiority over the reſt, but becauſe f our own more immediate dependence on him. n common with the other celeſtial bodies he has n apparent motion from eaſt to weſt, for we ſee im every day riſing in the eaſt, topping the ſky as t were archways, then deſcending till he ſets in he weſt.

If you conſider the *ſtars*, you will find that he greater part riſe and ſet every day; and after a few days obſervation, you will conclude that the ſtars have a motion common to all, by which they are carried round the earth in 24 hours.

If, in order to conſider more attentively the circumſtances of this diurnal motion, you place yourſelf in an elevated ſituation, you will perceive a circle terminating your view on all ſides by the meeting, or apparent meeting of the heaven and earth; your day and night depend upon it, it preſcribes to every ſtar in heaven the race that it has to run, and bounds your view ſo effectually that you can neither ſee whence they riſe, or whither they tend. This circle is called the *horizon*, it divides the heavens into two parts; but that part alone which is above the horizon is viſible, and as this part appears to us under the form of a concave hemiſphere, it is uſually termed the *viſible hemiſphere*.

On conſidering with attention for one or more nights the motion of the ſtars, you will find each ſtar deſcribing a circle in about 24 hours; thoſe ſtars that are moſt northward, deſcribe ſmaller circles than thoſe that are more to the ſouth; you will find the circles deſcribed by different ſtars diminiſhing gradually, till they are loſt and confounded in one point that is called the *pole* of the world. To be more particular, if you look towards the ſouth, you will obſerve ſome ſtars juſt appearing above the horizon, grazing this circle but not riſing above it, and then vaniſhing; obſerve a group a little farther from the ſouth, and you will find them riſe above the horizon, making a ſmall arch, and then going down; take another group ſtill more diſtant from the ſouth, and you will find theſe deſcribing a larger arch, and taking a longer time to go down. Turn now your face to the north, and you will find ſome that juſt ſkim he horizon, mount to the top of the heaven and

then

hen deſcend, and again touch the horizon and mount again without ever diſappearing; others that are higher than theſe, deſcribe complete circles in the ſky, without touching the horizon, and theſe circles diminiſh till at laſt you arrive at a ſtar that ſeems ſcarce to move from the point where it is ſtationed, the reſt wheeling round it; and you will find this race to be performed in about 24 hours.

To form clear ideas in aſtronomy, it is neceſſary for you to learn how to diſcover or diſtinguiſh the *pole* of the world, or the place in the ſtarry heaven correſponding thereto. The ſtar, you have already diſcovered, round which the others wheel, is very near the pole, and from hence has been called the *polar ſtar;* it never departs from it's ſituation, and every hour of the day, and every ſeaſon of the year, is to be found in the ſame place,* uniformly maintaining it's poſition. Now as there is one ſtar motionleſs at one end of the axis, there muſt undoubtedly be ſome point motionleſs at the other end of the axis.

The general appearance therefore of the ſtarry heavens, is that of a vaſt concave ſphere turning round two fixed points (diametrically oppoſite to each other, the one in the north, and the other in the ſouth) once in 24 hours.

This *pole-ſtar* is more or leſs elevated, according to the part of the earth from which it is viewed; thus, more northward, as at Lapland, it is much more elevated above the horizon than with us. If you go ſouthward, it is lower than with us; we ſee it more elevated than the inhabitants of Spain, and

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* This is ſpoke in conformity to the appearance of the object, for though this remarkable ſtar revolves round the pole, it's motion is ſo ſlow, and the circle it deſcribes ſo ſmall, as to render both the revolution and change of ſituation hardly perceivable.

theſe again ſee it more elevated than thoſe of Barbary. By continually travelling ſouthward, you would ſee the pole ſtar depreſſed to the horizon, and the other pole would appear in the ſouth part of the horizon, round which the ſtars in that part would revolve. There is, however, no ſtar in the ſouthern hemiſphere, ſo near the pole as that in the northern. If you were ſtill to travel onward to the ſouth, the north pole would diſappear, and the whole hemiſphere would appear to turn round a ſingle point in the ſouth, as the northern hemiſphere appears to turn round the pole-ſtar.

Here, however, it may be proper to obſerve, that what we call the *ſky*, in which the heavenly bodies ſeem as it were to be fixed, is no real ſubſtance. If there was no atmoſphere ſurrounding our earth, whoſe particles might reflect other rays of light to our eyes, than thoſe which come directly from the ſun, *all parts of the heavens, even at mid-day, would be dark, and the ſtars be viſible at noon.* But as our atmoſphere abounds with particles capable of reflecting light every way, ſome of it will fall upon our eyes whitherſover they are directed; from the nature of this reflection, we receive the idea of colour, and the mind immediately imagines a ſubſtance wherein it may reſide; in the ſame manner, the regular reflection of light from an object in a looking glaſs, is combined by the mind into an image of that object. Mr. de Sauſſure, when on the top of Mount Blanc, in Savoy, a mountain which is elevated 15673 feet perpendicularly above the ſea, and where conſequently the atmoſphere muſt be much rarer than our's, ſays, that the moon ſhone with the brighteſt ſplendor in the midſt of a ſky as dark as ebony, while Jupiter, rayed like the ſun, roſe from behind the mountains in the eaſt.

The polar ſtar may be diſcovered by a continual attention to the motions of the ſtars, as already deſcribed; but there is a readier method, by attending to thoſe ſtars that the country people call the waggon and horſes, but that aſtronomers call the *great bear*. It conſiſts of ſeven very conſpicuous ſtars: four of theſe make a kind of ſquare; prolong a ſtrait line through the two which are fartheſt from the three out of the ſquare, and it will at laſt reach a ſolitary ſtar, which, from it's vicinity to the pole, is called the *pole ſtar*. In early ages mariners had no other guide for their wandering veſſel; by this they formed their obſervations, and regulated their voyage. When this was for a length of time obſcured by clouds, they were bewildered on the watery waſte, and knew not where they were advanced, nor whither they ſhould ſteer; but when this auſpicious ſtar broke through the gloom, they re-aſſumed with alacrity the management of the helm, and ſhaped their courſe with tolerable ſatisfaction and certainty. It may be proper to obſerve to you, that the polar ſtar is always on the ſame ſide of the ſquare with the ſtar marked α on the celeſtial globe, or, which is the ſame thing, on the convex ſide of the bear's tail.

Knowing the pole-ſtar, you will be able to diſtinguiſh the *cardinal points*, the *north*, *ſouth*, *eaſt*, and *weſt*. 1. The *north*, the ſide to which you are turned when you look at the pole. 2. The *ſouth*, the oppoſite ſide, or that in which the ſun appears in the middle of the day. 3. The *eaſt*, that ſide on which the ſun appears to riſe. 4. The *weſt*, that ſide on which the ſun ſeems to ſet. The eaſt is on the right hand when you look at the pole, and the weſt on the left. The eaſt and weſt points are placed exactly at equal diſtances (or at right angles) from the north and ſouth.

The ancients, in Homer's time, divided the horizon into four cardinal points; afterwards they reckoned twelve; but in Pliny's time the common diviſion was into eight points. The earlieſt diviſion known to the ancients being the four cardinal points, eaſt, weſt, north, ſouth, winds were ſaid to blow from that point to which they were neareſt. Thus, the *eaſt wind* is ſaid "to have brought the locuſts in Egypt," though it was probably a north-eaſt wind. The horizon is now ſubdivided into thirty-two points, which are uſually termed *the points of the compaſs*; becauſe the compaſs ſhews in what part of the compaſs theſe points are ſituated.

In conſidering the heavens, aſtronomers find it neceſſary to ſpeak of a point ſuppoſed to be directly over our heads, and this point they call the *zenith*: it is the point where the thread of a *plumb-line* would meet the heavens, were it ſufficiently extended.

The *zenith* being the moſt elevated point of the heavens, is always ninety degrees, or a quarter of a circle, from every part of the horizon. If a ſtar, therefore, be found ſixty degrees above the horizon, it will be thirty degrees from the zenith; becauſe ſixty and thirty make the ninety, that is, the diſtance from the horizon to the zenith. In future, therefore, I may ſay, that the height or *altitude* of a ſtar is the *complement* of it's diſtance from the zenith, becauſe *the complement of an arch is what it wants of ninety degrees.*

The *nadir* is the loweſt point of the celeſtial ſphere; that which is directly under our feet, or oppoſite to the zenith, and towards which the plumb-line directs itſelf by it's natural gravity.

The zenith and nadir being directly oppoſed to each other, if you conceive a circle making the whole tour of the heavens, and paſſing through the zenith and nadir, there will be one hundred and eighty degrees, or a ſemicircle, on each ſide. All circles paſſing through the zenith and nadir are called *vertical circles*, becauſe the line through which a plumb-line paſſes is called a vertical line. The altitude of objects above the horizon is eſtimated by theſe vertical circles.

Whenever you conſider the heavens from any elevated ſituation, you naturally conceive, that as there is a hemiſphere above, there is alſo another beneath, though inviſible; and that of courſe the *horizon* is a great circle of the ſphere, dividing the concave heaven into two parts, the viſible above, the inviſible below; and conſequently that this circle determines the riſing and ſetting of every celeſtial body.

The earth being (as I ſhall hereafter prove to you) a ſpherical body, the horizon, or limit of our view, muſt change as we change our ſituation; every place upon the earth, every particular obſerver, has a different horizon. Thus, to an obſerver placed at a, *fig.* 2, *pl.* 3, the horizon is C C; but if he removes to B, his horizon will be H D.

As one pole ſuppoſes another, the *ſouth pole* is directly oppoſed to the other, and as much below the horizon as the north pole is above it: the north pole at London is about 51° 30′ above the horizon. Theſe two poles are the extremities of a line going from one to the other, through the center of the earth. This line is called the *axis* of the world; it is about this line that the whole heavens ſeem to turn every day.

Knowing the two extremities of the axis, it is eaſy to conceive a wheel or circle in the middle, between the two poles or extremities, and this will be the *equator*. To underſtand this more clearly, I muſt refer you to a diagram. Let H P Z E, *fig.* 5, *pl.* 3, repreſent a vertical circle, paſſing through the two poles, P the north pole, R the ſouth pole, P R the axis of the world; then the line E Q will repreſent the diameter of the equator, or of a circle into four parts; one from the time of their riſing to their arrival on the meridian; from this to their ſetting; thence to their reaching the lower meridian; and, laſtly, from thence to their riſing again the next day.

The meridian of a country ſituated eaſt or weſt of London, is a different one from that of London. If you travel eaſt or weſt, you change your meridian by a quantity equal to that which you have advanced towards the eaſt or the weſt; for your meridian, at every change of ſituation, paſſes through a new zenith, and the poles of the world. Thus Rome is about 12° 34″ eaſt of London, and conſequently the meridian of Rome differs 12° 34′ from that of London. There is but one method of changing your ſituation without changing your meridian; which is, to go directly north or ſouth, that is, towards either of the poles.

Every place is ſuppoſed to have a meridian paſſing over it's zenith, and going through the poles of the world. All the meridians therefore meet, and interſect each other, at the poles. They are all at right angles to the equator; and the equator, becauſe it is every where at an equal diſtance from the poles, divides every meridian into two equal parts.

You have now eſtabliſhed three circles in the celeſtial ſphere, to which you may refer all the ſtars you obſerve. Theſe circles, though in themſelves *imaginary*, will become, as it were, fixed points for your obſervations. The *horizon* is the firſt circle which you muſt uſe; not only as it diſtinguiſhes night from day, and the riſing and ſetting of all the heavenly bodies, but as the higher and farther they are elevated above the horizon, the longer they ſtay with us; their elevation above it became one of the firſt objects of an aſtronomer's attention: this was one of the means by which he could refer them to the horizon.

To this end, ſuppoſe a circle riſing perpendicularly out of the horizon, paſſing through the ſtar, and going up to a point directly over your head, or to your zenith. Upon this circle you may, by the help of your quadrant, reckon how many degrees it is from the horizon; and this is called it's *altitude*, or height. The circle upon which I count the degrees of altitude is called a *vertical* circle, becauſe it ſtands perpendicular to the horizon, and paſſes through the zenith.

Thus B D, *fig*, 3. *pl.* 14, is a quadrant whoſe circumference is divided into ninety degrees. Place one of the ſides vertically by the means of the plumb-line; put the eye at the center o; obſerve what point, c, on the circumference of the quadrant, correſponds with the ſtar, and the number of degrees between D and C will be the altitude of the ſtar above the horizon. For inſtance, if the arc D C is the half of B D on the ſmall inſtrument, the celeſtial arc A R will be alſo the half of Z R, both one and the other will be forty-five degrees; but as the MEASURE OF ANGLES, by a quadrant, or ſome other inſtrument, is the baſis of aſtronomy, it will be neceſſary to enter here ſomewhat fully into the nature thereof, before we proceed further in our inveſtigation of the heavens.

OF THE ASTRONOMICAL QUADRANT.

The ſmall quadrant before you, *fig.* 1, *pl.* 14, is a very ſimple and uſeful inſtrument. With it you may not only perform a great number of intereſting and entertaining problems,* but may alſo attain a good idea of practical aſtronomy.

Every

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* See my Eſſays on Aſtronomy, &c.

axis, it may be immediately placed in any vertical poſition, and the pedeſtal being moveable in the axis of the circle E F, at bottom, ſerves to place it in the direction of any azimuth, or towards any point of the compaſs. The limb A B is divided into degrees and halves, numbered from A; and upon the radius B C are fixed two ſights, of which B is perforated with a ſmall hole, and is provided with a dark glaſs, to defend the eye from the ſun's light; and the other ſight, C, has a larger hole, furniſhed with croſs wires, and alſo a ſmaller, which is of uſe to take the ſun's altitude, by the projection of the bright image of that luminary upon the oppoſite ſight. From the center C hangs a plumb-line C P. The horizontal circle F E is divided into four quadrants of ninety degrees; and an arm E, connected with the pedeſtal, moves along the limb, and conſequently ſhews the poſition of the place of the quadrant, as will hereafter be more minutely explained. Laſtly, the ſcrews G, H, I, render it very eaſy to ſet the whole inſtrument ſteadily and accurately in it's proper poſition, notwithſtanding any irregularity in the table or ſtand it may be placed upon.

The rationale of this inſtrument is very clear and obvious. It is uſed to meaſure the angular diſtance of any body, or appearance, either from the zenith or point immediately above our heads, or from the horizon or level. The plumb-line C P, if continued upwards from C, would be directed to the zenith Z; and the line C L, ſuppoſed to be drawn from the center of the quadrant to an object L, will form an angle L C Z, which is the zenith diſtance, and is equal to the angle B C P, formed between the oppoſite parts of the ſame lines. We ſee, therefore, that the degrees on the arc, comprehended on the limb of the quadrant, between the plumb-line and the extremities next the eye, meaſure the angle of the zenith diſtance.

Again, the line CK (forming a right angle with the perpendicular C Z) is *level*, or horizontal; the angle L C K muſt therefore be the *altitude* or elevation of L above the horizon; and this laſt angle muſt be equal to the angle meaſured between the plumb-line and the end A fartheſt from the eye; becauſe both theſe are equal to the quantity which would be left, after taking the zenith diſtance from a right angle, or the whole quadrant.

The determination of the altitude or zenith diſtance of an object is not ſufficient to aſcertain it's place, becauſe the object may be placed in any direction with reſpect to azimuth, or the points of the compaſs, without increaſe or diminution of it's altitude. Hence it is, that an horizontal graduated circle is a neceſſary addition to a quadrant, which is not intended to be always uſed in the ſame plane. The bearing or poſition of an object relative to the cardinal points, together with the altitude, is ſufficient to aſcertain the place of any object or phenomenon.

To adjuſt the quadrant for obſervation. The quadrant is adjuſted for obſervation when it's plane continues perpendicular to the horizon, in all poſitions of the line of ſight. For this purpoſe, bring the index to 90° on the horizon, and turn one or both of the ſcrews which are fixed oppoſite 60°, till the plumb-line lightly touches the plane of the quadrant. Then turn the index to 0°, and make the ſame adjuſtment, by means of the ſcrew at 0°, and the quadrant is ready for obſervation.

Or otherwiſe, ſet the index at 0°, and obſerve the degree marked by the plumb-line on the limb: then turn the index to the other 0° which is diametrically oppoſite, and obſerve the degree marked by the plumb-line: if it be the ſame as before, there will be no occaſion to alter the ſcrews at 60°; but if otherwiſe, one or both of thoſe ſcrews muſt be turned, till the plumb-line interſects the middle degree (or part) between the two. After this operation, the degree marked by the plumb-line muſt be obſerved, as before, by ſetting the index at both the 90°, and the adjuſtment of the plumb-line to the middle diſtance muſt be made by the ſcrew at O, taking care not to touch the other ſcrews.

The latter method of adjuſtment being more accurate in practice, may be uſed after the former.

TO FIND THE ALTITUDE OF THE SUN, OR ANY OTHER CELESTIAL BODY.

The quadrant being adjuſted, as it muſt be in all caſes previous to it's uſe, the celeſtial body muſt be viewed through the ſights, and the plumb-line will ſhew it's altitude on the graduated limb of the inſtrument.

If the obſervation be made on the ſun, the dark glaſs muſt be uſed to defend the eye; or the luminous ſpot formed by the ſmaller hole of the ſight, which carries the croſs wires, muſt be made to fall on the mark on the other ſight, which lies immediately beneath the eye-hole.

CONTINUATION OF A VIEW OF THE GENERAL PRINCIPLES.

Let us now return to our obſervation on the *celeſtial ſphere*: whilſt this ſphere turns upon it's *poles*, the points ſituated in the equator deſcribe a circle, which is of the ſame ſize with the ſphere, it's center paſſing through the center of the ſphere; the points which are nearer the pole deſcribe ller circles, theſe are called *parallels to the equa-* or ſimply parallels. Every point in the hea-s, that is not ſituated in the equator, deſcribes parallel; theſe diminiſh in ſize, in proportion as ey are more diſtant from the equator.

All theſe parallels are divided into equal parts y the meridian; thus, any ſtar ſuppoſed on the eridian, will deſcribe by it's diurnal motion a ircle parallel to the equator, and will be as long n one ſide of the meridian as it is on the other; his circle dividing the time of the diurnal revolu-ion into two equal parts.

If the parallel deſcribed by the ſtar be entire-y above the horizon, you may ſee it paſs the me-idian twice in the day; once in that part of the meridian above the pole, once in that part of the meridian below the pole. But if part of the pa-allel deſcribed by the ſtar be below the horizon, ou will only ſee it paſs the meridian once in 24 hours.

Mathematicians call all thoſe circles on the ſurface of the ſphere, whoſe center paſſes through he center of the ſphere, *great circles;* the plane of theſe circles divides the ſphere into two equal arts. The *equator*, the *meridian*, and the *horizon*, re great circles. *Small circles* are thoſe which divide the ſphere into two unequal ſegments; ſuch are the parallels to the equator.

TO FIND THE HEIGHT OF THE POLE BY MEANS OF THE STARS.

The diſpoſition of the three great circles of the ſphere that we have fixed upon, namely, the *quator*, the *horizon*, and the *meridian*, will hence-forth become the baſis of all your obſervations; and to theſe you will refer the ſtars, in order to determine their ſituations and motions. The firſt thing, therefore, we ought to do, is to diſcover the reciprocal ſituation of theſe circles: 1. The ſituation of the equator with reſpect to our horizon. 2. The elevation of the pole. 3. The elevation of the equator at the meridian, or ſouth point.

If the north or pole-ſtar, of which we have already ſpoken, had been preciſely and accurately ſituated at the pole of the world, it would have been a ſure and permanent mark, and you would have had nothing more than to have taken the altitude of this ſtar to have obtained that of the pole; but this ſtar is two degrees diſtant from the pole. To the naked eye, unaſſiſted with inſtruments, this difference can ſcarce be perceived; but with inſtruments, and by attentive obſervation, it is found to deſcribe a ſmall circle about the pole, ſo that though it does not mark directly the pole; yet the middle of the circle it deſcribes being the pole, it's place may be very readily diſcovered.

Thus the pole-ſtar deſcribing about the pole, a circle of 2° diſtant from the pole, there will be 4° difference between the altitude of this ſtar when it is in the upper point of it's circle, and when it is in the loweſt point, being 2° on each ſide the pole. If therefore the altitudes be taken when it is in both ſituations, in order to have the height of the pole, you muſt ſubtract 2° from the ſuperior altitude, and add two to the lower; thus, if the altitude had been obſerved at London firſt to be 53° 32′, and then 49° 32′, the difference is 4°, the half of which added to 49° 32′, or ſubtracted from 53° 32′, gives 51° 32′, the altitude of the pole at London; or you may add the two heights together, and take the half. The elevation of the pole may be diſcovered in the ſame manner by any other of the circumpolar ſtars.

The elevation of the pole being diſcovered, you thereby obtain that of the equator. Thus, in the diagram before you, *fig.* 5, *pl.* 3, P repreſents the pole, and E Q the equator, H O the horizon, P H the elevation of the pole, Z the zenith; H Z O, or the viſible part of the heavens, contains twice 90 or 180°, it being 90° from Z to H, and 90° from Z to O; but it is alſo 90° from the pole P, to E the equator. If you take away P E, there remains 90° for the other two arcs, or in other words, the elevation of the pole and the equator are together equal to 90°; and the one being known and ſubtracted from 90°, gives the other; in technical words, *the elevation of the pole is the complement of the elevation of the equator.*

It follows from hence, that the elevation of the equator is equal to the diſtance from the pole to the zenith, for the elevation of the equator is the difference between that of the pole and 90°; the ſame elevation ſubtracted from 90°, gives it's diſtance from the zenith.

For the ſame reaſon the diſtance from the equator to the zenith is equal to the elevation of the pole, for H Z is equal to 90°, and P E is equal to 90°; if, therefore, you take away P Z, which is common to both, the remainders P H, Z E, muſt be equal to each other.

OF THE APPARENT PHENOMENA OF THE MOON.

From conſidering the diurnal motion which is common to all the ſtars, and obvious even to thoſe who have given very little attention to theſe ſubjects, I ſhall paſs on to that motion of the planets which is performed in a *direction contrary to the diurnal revolutions of the ſtars*, that is, from weſt to eaſt.

Among theſe there are none ſo remarkable as thoſe of the moon; every month ſhe changes her figure, and makes the tour of the heaven in a contrary direction to the general motion thereof; ſo that though the moon appears to riſe and ſet every day like the other ſtars, by a motion from eaſt to weſt, yet ſhe ſeems alſo every day to be retarded in her motion, and to ſtay as it were behind the ſtars, or go backwards towards the eaſt about 13°.

This motion of the moon towards the eaſt, at the ſame time that it partakes of the general diurnal motion, is called her *periodical* motion, and is ſo conſiderable, that in 27 days, the moon, which appeared near any remarkable ſtar, ſeparates from it, moving in a contrary direction; the firſt day it removes rather more than 13 degrees from it, the ſecond 26, the third 39, &c. ſo that in 27 days it completes the 360, and meets the ſtar on the oppoſite ſide, having made the tour of the heaven.

“Her nightly changes in her circling orb” is a phenomenon ſtill more ſtriking than the preceding. At the new moon, as ſoon as ſhe becomes viſible ſhe is ſeen in the weſtern part of the heavens, at no great diſtance from the ſun, and juſt as it were immerged from his light. She increaſes every night in ſize, and removes farther and farther from the ſun, till at laſt ſhe appears in the eaſtern part of the horizon, when the ſun is diſappearing in the weſtern, riſing at the ſame time he ſets, and appearing with a full round face, equalling if not exceeding the ſun in ſize. After this ſhe gradually removes further and further eaſtward, till at laſt ſhe ſeems to approach the ſun as nearly in the eaſt as ſhe did before in the weſt, and riſes only a little before him in the morning; whereas in the firſt part of her courſe, ſhe ſet in the weſt long after him. This is a prelude to her total diſappearance, and though from her firſt appearance in the weſt ſhe takes almoſt a month to paſs to the eaſtern part of the heavens, ſhe ſeems to paſs from the eaſtern to the weſtern in one or two days; for immediately on her vaniſhing in the eaſt, ſhe appears again in the weſt, and very near the ſun. All theſe different appearances happen in the ſpace of a month, after which they recommence in the ſame manner. " Sometimes ſhe half reſtores day with her waxing brightneſs; ſometimes waning into dimneſs, ſhe ſcarcely diſperſes the nocturnal gloom."

This luminary, like the ſun, ſeems to have a motion from north to ſouth, but at oppoſite ſeaſons; for at ſummer time ſhe is low in the ſouthern part of the heavens, but approaches conſiderably nearer to the northern regions in winter. By her phaſes ſhe divides the times and ſeaſons, and we find that in early ages men were much affected with this twofold conſideration of the ſervices of the moon, enlightening the night, and regulating their time. I need not here mention the various ſacrifices, offerings, and proceſſions, in honour of Diana, Luna, Hecate, that is, of the moon under different names; her votaries were numerous and ſuperſtitious. Ignorant of philoſophical truth, and uninſtructed by revelation, they practiſed abſurdities, and believed in lies.

OF THE SUN'S ANNUAL MOTION, AND OF THE ECLIPTIC.

Though the periodical motion of the moon is quick and remarkable, yet there is ſtill one more important, that is, the apparent periodic or annual motion of the ſun; on it depend the changes of ſeaſon, the ſummer's heat and winter's cold, the different lengths of day and night. This motion is indeed only apparent, ariſing from the annual motion of the earth; at preſent, however, we are only conſidering appearances, from theſe we ſhall afterwards aſcend to the contemplation of the cauſes which occaſion them.

A little attention will ſoon convince you, that the ſun does not riſe exactly at the ſame point *of the heaven.*

Thus if you commence your obſervations of the ſun, for inſtance, in the beginning of March, you will find him appear to riſe more to the northward every day, to continue longer above the horizon, to be more vertical, or higher, at mid-day; this continues till towards the end of June, when he moves backward in the ſame manner, and continues this retrograde motion till near the end of December, when he begins to move forwards, and ſo on.

It is this change in the ſun's place, that occaſions him to riſe and ſet in different parts of the horizon, at different times of the year. It is from hence that his height is ſo much greater in ſummer than in winter. In a word, the change of the ſun's place in the heavens is the cauſe of the different length in the days and nights, and the viciſſitudes of the ſeaſons. "Sometimes we perceive him very high therein, as if he would come over our heads; at theſe times his rays fall upon us with greater force, he continues longer viſible, the earth and air are conſiderably heated, vegetables flouriſh and arrive at their perfect ſtate, every animal ſeems cheerful, and this agreeable ſeaſon we call *ſummer.* By and by, however, he removes farther ſouth, his time of continuing viſible becomes conſtantly ſhorter and ſhorter, until at laſt it is reduced to a few hours; the ſun is then ſunk almoſt in the ſouthern part of the heavens, the earth is covered with froſt and ſnow, the air is diſturbed with violent winds and tempeſts, vegetables periſh, animals are benumbed with cold, and we call this dreary ſeaſon *winter*. The intermediate ſeaſon, when the ſun begins to return towards us, and by his genial influence to revive the animal and vegetable world, is called *ſpring*. The ſeaſon when he again begins to withdraw his influence, when fruits ripen, and vegetable life begins to decay, is named *autumn*.*

As the knowledge of the ſun's apparent motion is of great importance, and a proper conception of it abſolutely neceſſary, in order to form a true idea of the phenomena of the heavens, you will excuſe my dwelling ſomething longer upon it. If on an evening you notice ſome fixed ſtar near the place where the ſun ſets, and obſerve it for ſeveral ſucceſſive evenings, you will find that it approaches the ſun from day to day, till at laſt it will diſappear, being effaced by his light, though but a few days before it was at a ſufficient diſtance from him. That it is the ſun which approaches the ſtars, and not the ſtars the ſun, is plain, for this reaſon; the ſtars always riſe and ſet every day at the ſame points of the horizon, oppoſite to the ſame terreſtrial objects, and are always at the ſame diſtance from each other; whereas the ſun is continually changing both the place of riſing and ſetting, and it's diſtance from the ſtars.

The ſun advances nearly *one degree* every day, moving from weſt to eaſt, ſo that in 365 days you will ſee the ſame ſtar near the ſetting ſun, as you obſerved to be near him on the ſame day in the preceding year. In other words, the ſun has returned to the place from whence he ſet out, or made what we call his *annual revolution*.

We cannot indeed obſerve the ſun's motion among the fixed ſtars, becauſe he darkens the heavens by his ſplendor, and effaces the feeble light of thoſe ſtars that are in his neighbourhood; but we can obſerve the inſtant of his coming to the meridian, and his meridianal altitude; we can alſo compute what point of the ſtarry heaven comes to the ſame meridian, at the ſame time, and with the ſame altitude. The ſun muſt be at that point of the ſtarry heavens thus diſcovered. Or we can obſerve that point in the heavens, which comes to the meridian at midnight, with a declination as far from the equator on one ſide, as the ſun's is on the other ſide; and it is evident, the ſun muſt be in that part of the heavens which is diametrically oppoſite to this point. By either of theſe methods you may obtain a ſeries of points in the heavens through which the ſun paſſes, forming a circle called the *ecliptic*.

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* New and Conciſe Syſtem of Geography. Edinburgh.

To combine more clearly the *annual* and *diurnal* motion of the ſun, let us conſider for a moment this globe; by turning it on it's axis you obtain an idea of the diurnal motion of the celeſtial ſphere. If you place an inſect at an equal diſtance from the poles, it will turn with the globe, and deſcribe the equator; if you place another nearer the poles, it will deſcribe a *parallel* to the equator. But while the globe is moving in one direction, the inſect may be moving very ſlowly in another, and will thereby imitate the *annual* motion of the ſun, which advances by degrees towards the eaſt, though it is carried round every day by the diurnal motion towards the weſt.

The *ecliptic*, or path of the apparent annual motion of the ſun, differs in ſituation from the equator, whoſe ſituation we have already aſcertained. This the Chaldeans firſt obſerved at Babylon, where the equator was elevated 54° above the horizon; now if the annual path of the ſun had been in the equator, every day at noon the ſun's altitude would have been 54°; it was ſo far from this, that in ſummer they found it riſe 24° above the equator, and in winter deſcend 24° below it; ſo that his meridian height in ſummer was 78°, and only 30° in winter; the ecliptic was therefore evidently differently ſituated from the equator, but cut it in two points diametrically oppoſite; for they obſerved twice in the year, in ſpring and autumn, that at noon the ſun's altitude was exactly the ſame with that of the equator.

The *ecliptic*, or path of the ſun, is then that circle of the ſphere which cuts the equator in two points, but which is afterwards removed about 24° from the equator, being one part of the year on the north ſide, the other half on the ſouth ſide; and as the points where it cuts the equator divide it into two equal parts, you may conclude that the ecliptic is a *great* circle of the ſphere, for it is one of their properties to biſect each other. The next buſineſs is to determine in the celeſtial concave, and among the fixed ſtars, thoſe by which the ſun paſſes every day ſo as to delineate his path on a globe.

For this purpoſe, remember there are two days, ſix months diſtant from each other, when the meridian altitude of the ſun is the ſame with that of the equator; theſe are called the *equinoctial days*, becauſe the ſun on thoſe days deſcribing the equator is twelve hours above, and twelve beneath the horizon, ſo that the day is equal to the night; one is called the *vernal*, the other the *autumnal equinox*.

Having remarked at midnight on the vernal equinox a ſtar having the ſame altitude with the ſun, that is, equal to the elevation of the equator, you are certain of having obtained the point diametrically oppoſite to the ſun, that, where he will be at the autumnal equinox. In the ſame way you may diſcover at the autumnal the ſun's place at the vernal equinox, and thus aſcertain two points eſſential to the progreſs of aſtronomy.

The points of the ecliptic where the ſun is ſituated when he is moſt diſtant from the equator, are called *ſolſtitial* points; they are called the ſolſtitial points, becauſe the ſun at theſe points appears ſtationary for ſome days, that is, about the 21ſt of June, and the 21ſt of December. Theſe points being obſerved, there remains, for compleating the ecliptic, only to fill up the intermediate parts of the path.

The diſtance between the equator and the ecliptic at the ſolſtitial points, is called the *obliquity of the ecliptic*; to aſcertain this, it is neceſſary to meaſure how much the ſun riſes above the equator in ſummer, and deſcends below it in winter; or how much higher he was at noon in ſummer than in winter. Aſtronomers have done this, and found the difference to be 47 degrees, the half of which 23 ½ is the greateſt diſtance between the ecliptic and the equator.

About 2000 years ago this obliquity was 24°, it is now about 23° 28′, and diminiſhes about 1 minute every 100 years.

To reckon and meaſure the motion of the ſun and other celeſtial bodies, it is neceſſary to fix upon ſome point in the heavens from whence to proceed, and to which every thing may be referred. The return of the ſeaſons being the moſt remarkable and intereſting circumſtance in all aſtronomy, the departure of the reckoning was governed thereby.

The ſun by his annual courſe in the ecliptic traverſes the equator every year, bringing ſpring with him; and this renewal of nature ſerved to mark the beginning of the year, and the aſtronomers uſed the point where this change took place, or the interſection of the equator and ecliptic for the beginning of their meaſures, and called *longitude* the diſtance of the ſun from the vernal equinox reckoned along the ecliptic.

OF THE PLANETS.

The diurnal motion of the heavens, as being the moſt ſtriking, was that which was firſt noticed by mankind: then the periodic motions of the ſun and moon. In proceſs of time, by repeated and more a[illegible]uous obſervations, they found among the ſtars ſix which had motions peculiar to themſelves, and theſe they called *planets*; they are thus named, Mercury ☿, Venus ♀, Mars ♂, Jupiter ♃, Saturn ♄, and one lately diſcovered is named, the Georgium Sidus ♅; they never depart far from the ecliptic, their motions are very irregular, ſometimes they appear to go *forwards*, ſometimes *backwards*, and ſometimes to be *ſtationary*.

MERCURY emits a bright white light, but keeps ſo near the ſun, that he is very ſeldom viſible; and when he does make his appearance, his motion towards the ſun is ſo ſwift, that he can only be diſcerned for a *ſhort time*. He appears a little after ſun-ſet, and again a little before ſun-riſe.

VENUS is the moſt beautiful ſtar in the heavens, known by the names of the *morning* and *evening* ſtar. She alſo, like Mercury, keeps near the ſun, though ſhe recedes from him much further, and like him, is never ſeen in the eaſtern quarter of the heavens when the ſun is in the weſtern; but always either attends him in the *evening*, or gives notice of his approach in the *morning*.

MARS is of a red fiery colour, giving a much duller light than VENUS, though he ſometimes appears circles may be deſcribed; thoſe circles, whoſe *center* is the ſame with the *center* of the globe, are called by way of diſtinction *great circles*, theſe divide the ſphere into two equal parts. The angular diſtance of two points, ſituated on the ſurface of the ſphere, is meaſured by the arc of a great circle intercepted between them.

Leſſer circles divide the ſphere into two unequal parts.

The ſphere before you, by it's *real* circles, ſerves to repreſent, and will enable me to explain to you, thoſe *imaginary* circles by which aſtronomers divide the heavens, into the ſame parts or portions as you ſee theſe circles divide the ſphere. If your eye could be placed in the center of this ſphere, you would ſee it's circles upon or againſt thoſe very points of the heavens where the imaginary circles of the aſtronomers are ſuppoſed to be ſituated. It is called armillary, becauſe it conſiſts of a number of rings of braſs, called by the Latins *armillæ*, from their reſembling bracelets or rings for the arms.

There are *ſix great circles* of the ſphere which require your particular attention: the horizon, the meridian, the equator, the ecliptic, the equinoctial colure, the ſolſtitial colure.

The ſphere is ſuſtained in a frame, on the top of which is a broad circle repreſenting the *horizon.*

On the inſide of the horizon are two notches for receiving a ſtrong braſs circle repreſenting the *meridian.*

It is ſuſpended on *two pins*, at two oppoſite points of the meridian; theſe pins are a continuation of the axis of the ſphere both ways, and as the ſphere turns round upon them, they are conſidered as *poles*, and are called the one the *north*, the other the *ſouth* pole.

The *equator* is that circle which goes round ſphere exactly in the middle between the two les.

The *ecliptic* is that circle which croſſes the uator obliquely; it is divided into twelve parts, h of which conſiſts of thirty degrees.

The *equinoctial colure* is the great circle which ſſes through thoſe two points of the equator that intercepted by the ecliptic.

The ſolſtitial colure is the other great circle right angles to the equator.

There are four leſſer circles of the ſphere, two pics, and two polar circles; theſe four circles all parallel to the equator.

The *tropic of cancer* is the parallel which is the north ſide of the equator, and 23 ½ degrees tant therefrom.

The *tropic of capricorn* is ſituated on the th ſide of the equator, and 23 ½ degrees therem.

The two *polar circles* are at the ſame diſtance m the two poles as the tropics are from the uator, that is, twenty-three degrees and a half.

That towards the *north* pole is called the *arc- circle*, that towards the *ſouth* pole the *antarctic cle.*

OF THE HORIZON AND IT'S USES.

This broad circle is termed the horizon, beſe it repreſents that imaginary circle which unds or terminates the view of the ſpectator, iding the ſphere into two equal parts; that ich is above the horizon is called the upper or ible hemiſphere, that which is below, the lower inviſible hemiſphere. When the ſun, moon, or rs deſcend below this circle, we ſay, *they are ſet*;

on the contrary, when they appear above it, ſay, *they riſe.*

The poles of the horizon are the two p every where equally diſtant from it; 1. the *zenit* the point directly over the head of the ſpe and, 2. the *nadir*, or the point directly und feet.

On the broad circle repreſenting the hori are marked the thirty-two points of the mari compaſs; the eaſt, weſt, north, and ſouth poi are principally to be regarded; theſe are call cardinal points. Thus to refer the celeſtial bodi to the horizon, it is uſual in aſtronomy to ſay, th ſun, moon, or planets, riſe on ſuch a point, or many points from the eaſt or weſt, north or ſouth If you conſider their diſtance from the eaſt and w points of the horizon, it is called their *amplitude*; the *azimuth* is their diſtance from the meridian reckoned on the horizon.

OF THE DISTINCTION OF THE HORIZON INTO RATIONAL AND SENSIBLE.

In general terms, the horizon may be defined to be an imaginary circle, that ſeparates the viſible from the inviſible part of the heavens.

If you ſuppoſe the floor or plane, on which you ſtand, to be extended every way, till it reach the ſtarry heavens, this plane is your SENSIBLE HORIZON.

The RATIONAL HORIZON is a circle, whoſe plane is parallel to the former, but paſſing through the center of the earth.

The rational horizon divides the concav ſphere of the heavens into equal parts, or hemiſpheres; the objects that are in the upper hemi

ſpher

ſphere will be viſible; ſuch as are in the lower hemiſphere will be inviſible.

Though the globe of the earth appears ſo large to thoſe who inhabit it, yet it is ſo minute a ſpeck, when compared to the immenſe ſphere of the heavens, that at that diſtance the planes of the rational and ſenſible horizons coincide; or in other words, the diſtance between them in the ſphere of the heavens, *is too ſmall for admeaſurement.*

To illuſtrate this, let A B C D, *fig.* 1, *pl.* 3, repreſent the earth; z h n o, the ſphere of the ſtarry heaven. If an inhabitant of the earth ſtands upon the point A, his ſenſible horizon is *ſe*, his rational one h o; the diſtance between the planes of theſe two horizons is A F the ſemidiameter of the earth, which is meaſured in a great circle upon the ſphere of the heaven, by the angle e F o, or the arc e o; this arch in ſo ſmall a circle, as z h n o, would amount to ſeveral degrees, and conſequently the difference between the ſenſible and the rational horizon would be great enough to be meaſured by obſervation. If we repreſent the ſphere of the heaven by a larger circle, the ſemidiameter of the earth A F meaſured in this circle, will amount to fewer degrees; for the arc E O is leſs than the arc e o; and the larger the ſphere of the heaven is, in proportion to the globe of the earth, the leſs ſenſible is the difference betwen the two horizons. Now as the ſphere of the earth is but as a point, when compared to the ſtarry heaven, the difference between the ſenſible and rational horizon will be inſenſible.

From what has been ſaid, it appears that the only diſtinction between the ſenſible and rational horizon, ariſes from the diſtance of the object we are looking at.

The SENSIBLE HORIZON is an imaginary circle, which terminates our view, when the objects we are looking at are upon the *earth's ſurface.*

The RATIONAL HORIZON is an imaginary circle, which terminates our view, when the objects we are looking at are as *remote as the heavenly bodies.*

As the rational horizon divides the apparent celeſtial ſphere into two equal hemiſpheres, and ſerves as a boundary, from which to meaſure the elevation or depreſſion of celeſtial objects; thoſe in the upper or viſible hemiſphere are ſaid to be high or elevated above the horizon; and thoſe in the other hemiſphere are called low, or below the horizon.

The earth being a ſpherical body, the horizon, or limits of our view, muſt change as we change our place; and therefore every place upon the earth has a different horizon. Thus if a man lives at a, *fig.* 2, *pl.* 3, his horizon is G C; if he lives at b, his horizon is H D; if at c, it is A E. From hence we obtain a proof of the ſphericity of the earth; for if it were flat, all the inhabitants thereof would have the ſame horizon.

The point in the heavens, which is directly over the head of a ſpectator, is called the ZENITH.

That point, which is directly under his feet, is called the NADIR.

If a man lives at a, *fig.* 2, *pl.* 3, his zenith is A, his nadir E. If he lives at b, his zenith is B, his nadir F; conſequently the zenith and horizon of an obſerver remains *fixed* in the heavens, ſo long as he continues in the *ſame place*; but he no ſooner *changes* his poſition, than the horizon touches the earth in another point, and his zenith anſwers to a different point in the heavens.

Of

the ecliptic, which repreſents the ſun's path, cuts this circle in two oppoſite points, and therefore of courſe the ſun is twice a year in this circle; and as one *half* of this circle is always above the horizon, and the other half below it, when the ſun is in thoſe two points the days and nights will be equal. This circle is called the *equator,* becauſe it equates or divides the globe of the earth into two equal parts; it is often alſo called the *equinoctial,* becauſe that when the ſun is in this circle the days are equal to the nights.

It is divided into 360 degrees, beginning and ending in the equinox point, and numbered from weſt to eaſt; theſe degrees on the ſphere are called degrees of *right aſcenſion,* but the degrees on the equator laid down on a terreſtrial globe are called degrees of *longitude.*

Hence a meridian paſſing through the *ſun, planets,* or *ſtars,* ſhews on the equator the degree of it's *right aſcenſion,* or diſtance from the equinoctial point.

OF THE HOUR CIRCLE.

There is a ſmall circle fixed about the north pole, and a hand on the axis of the ſphere, ſo that by turning the ſphere on it's axis, the index will be carried round the circle.

This circle is uſed to convert the *degrees* of the equator *into time;* it is divided into twenty-four equal parts, anſwering to twenty-four hours, or the time of an entire revolution of the heavens. The index, by pointing ſucceſſively to thoſe hours, ſhews in what ſpace of time any part of that revolution is performed.

The twelve hours are twice engraved on this circle; the firſt twelve hours ſhew the time from noon to midnight, the other from midnight to noon the next day.

Aſtronomers begin the day at noon, therefore the two hours of twelve ſtand directly upon the graduated edge of the meridian.

To find the time in which any motion is performed, I bring the beginning of the degrees on the equator to the meridian; holding the ſphere in that poſition, I turn the index about to the hour of twelve upon that edge of the meridian next me; I now turn the ſphere once round, till the ſame point comes again to the meridian, and the index paſſes once round the hour circle, which ſhews that *one revolution of the ſphere is performed in twenty-four hours.*

If one revolution, or three hundred and ſixty degrees, be made in twenty-four hours, then half a revolution, or one hundred and eighty degrees, is made in twelve hours; a quarter, or ninety degrees, in ſix hours; and in that proportion fifteen degrees of the equator paſs the meridian in one hour and fifteen minutes, or one quarter of a degree in one minute of time.

Of the Quadrant of Altitude.

This is, you ſee, a long ſlip of braſs with a nut at top to fix it to the meridian; it is divided into ninety degrees, and being fixed at the zenith it reaches to the horizon; it may be carried to any part of the ſphere, and ſo will ſhew the height or altitude of any point above the horizon in any poſition of the ſphere.

OF THE ECLIPTIC AND CELESTIAL LONGITUDE.

We are now come to the great circle called the *ecliptic*, becauſe there can be no eclipſes of the ſun and moon, but when the moon is in or near this circle; for this circle repreſents the ſun's apparent annual path, and therefore whenever the moon obſcures the ſun, or is obſcured by him, ſhe muſt be near thereto.

It is generally graduated into twelve equal parts, conſiſting of thirty degrees each, the beginning of the part being marked with characters repreſenting the twelve ſigns. Aſtronomers divided the ecliptic in this manner in order to judge more eaſily, and expreſs more clearly the places of the ſun, moon, and planets; for it is eaſier to obtain an idea of their ſituation by referring them to ſome part of a known figure, than it could poſſibly be by merely conſidering degrees in the circumference and expanſe of the heaven. The aſtronomers, therefore, to reduce the ſcience to order and method, arranged the ſtars, which are diſtributed irregularly over the ſurface of the ſkies, into certain and determinate claſſes of conſtellations.

Thus the ſtars near the ecliptic are diſtributed into twelve conſtellations or ſigns, which are named, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Piſces.

The ſun appears always in this circle, advancing in it nearly a degree in a day, and going through it exactly in a year. The points where this circle cuts the equator are called the equinoctial points; the vernal equinoctial point is marked *Aries*, the autumnal one *Libra*.

It is by the ecliptic that aſtronomers eſtimate the *latitude* and *longitude* of the heavenly bodies.

The *longitude* of the heavenly bodies is reckoned in ſigns and degrees of the ecliptic, beginning from the firſt point of Aries, or vernal equinoctial point. Thus ſuppoſe the ſun be now in the fifth degree of Leo, we ſay, his *longitude is four ſigns, four degrees, and part of another*; for he has already paſſed the four ſigns of Aries, Taurus, Gemini, Cancer, and four degrees of Leo, and is in the fifth.

The *latitude* of the heavenly bodies is reckoned in an arch of a great circle paſſing through the pole of the ecliptic and a given ſtar, intercepted between the ecliptic and the ſtar.

The *zodiac* is a broad circle in the heavens, and which is ſometimes applied to an armillary ſphere; it contains the twelve ſigns, and is called the zodiac, becauſe, according to the Chaldean diviſion, it conſiſted only of animal figures; what is now called *Libra*, being by them reckoned a part of *Scorpio*, and making the claws of that animal.

The diviſion of the zodiac into twelve parts correſponds with the diviſion of the year into twelve months, and therefore plainly anſwers to the apparent motion of the ſun. This zone repreſents the ſpace or limits to which the planets ſtay on each ſide the ecliptic, which is about five degrees, ſo that the breadth thereof is about ten degrees.

OF THE COLURES, TROPICS, AND POLAR CIRCLES.

The next circles of the ſphere we are to conſider are thoſe two called the *colures*, both of which paſs through the poles of the world, and cut the equator at right angles.

One of theſe paſſes through the equinoctial points, and is called the *equinoctial colure*; the other paſſes through the ſolſtitial point, and is called the *ſolſtitial colure.*

The *colures* are in a manner the boundaries of the year, for they point out the ſeaſons by their two oppoſite parts of the ecliptic. The ſolſtitial colure paſſes through the poles of the ecliptic.

The *two tropics* are parallels, and diſtant 23½ degrees from the equator on each ſide of it, at which diſtance they touch the ecliptic in the *ſolſtitial points.*

While the ſun is going from Aries to Cancer, he advances every day more northward, till he comes to Cancer his moſt northward ſituation; after which he begins to deſcend to *Libra*, getting every day more ſouthward than before. Now when he is in the beginning of Cancer, he changes his motion, and turns from going northward to go ſouthward; this turning back is meant by the word *tropic*, from whence the parallel paſſing through Cancer is called *the tropic of Cancer*; and for the ſame reaſon the other is called the *tropic of Capricorn*, becauſe there the ſun returns from the ſoutherly courſe to the northern one.

On the ſphere they repreſent the parallels in which the ſun moves on the *longeſt and ſhorteſt days in the year*; in other words, when he has the greateſt and leaſt meridian altitude, that part of the tropic which is above the horizon repreſents the length of the day, and that part which is beneath the horizon repreſents the night. Now you muſt obſerve from the ſphere, that the day is the longeſt when the ſun is in the tropic of Cancer, and the night the ſhorteſt of all others in the year; in the ſame manner the two parts of the tropic of Capricorn ſhew the longeſt day, and ſhorteſt night of the year.

The *polar circles* are two imaginary circles in the heavens, which correſpond to thoſe parts of the earth that were termed by the ancients the *frigid zones*; they include 23½ degrees on each ſide their reſpective poles.

These circles have been by many authors called the *arctic and antarctic circles*, but improperly, as the ancients always meant by the arctic circle the largeſt parallel that was always above the horizon of any particular place, containing all thoſe ſtars which never ſet at that place, but ſeem to be carried round above our horizon in circles parallel to the equator.

The largeſt parallel which is entirely hid below the horizon of any place, they called the antarctic circle, or circle of perpetual occultation. This includes all the ſtars which never riſe to an inhabitant of the northern hemiſphere, but are perpetually below the horizon.

All arctic circles touch their horizons in the north point, and all antarctic circles touch their horizons in the ſouth point.

Thoſe who live under either tropic, have one of the polar circles for their arctic, and the other for their antarctic circle; thus the names of *mutable* circles have been given to the immutable polar circles, which are only arctic and antarctic circles in one particular caſe.

OF A RIGHT, PARALLEL AND OBLIQUE SPHERE,

There are three ſituations of the celeſtial ſphere relative to the inhabitants of the earth, of which you may form a very clear conception by means of the *armillary ſphere*.

Of a right ſphere, or of theſe inhabitants who live under the equator. To ſhew the poſition of the circles of the ſphere with reſpect to theſe inhabitants,

bitants, bring the equator into the zenith, and the poles of the world lie in the horizon. The equator, the tropics, and polar circles, all ſtand perpendicular to the horizon; the heavenly bodies always riſe and ſet perpendicularly; and as the horizon cuts all the circles in half, the days and nights will be equal throughout the whole year. This poſition is called a *right ſphere.*

Under the equator the ſtars muſt every day appear to riſe out of the horizon, then to aſcend perpendicularly for ſix hours, and deſcend perpendicularly for the ſix following hours, ſet and remain below the horizon twelve hours ſucceſſively. The planets do the ſame, there being no difference between them and the fixed ſtars, but that the latter always deſcribe the ſame parallel; whereas the parallels deſcribed by the former differ every day, being greater or leſs according to their diſtance from the equator.

A parallel ſphere. This poſition is to ſhew the ſituation of the heavens to an inhabitant who lives under the poles; bring the pole therefore in the zenith, the axis is now at right angles to the horizon, the equator and horizon coincide, and the tropic and polar circles are parallel thereto; here there will be but one day and night throughout the whole year: for the ſame reaſon the moon, in *half* her monthly revolution, will never *riſe*, and in the other *half* will never *ſet.* The fixed ſtars will every day deſcribe circles parallel to the horizon, ſome never *riſing*, others never *ſetting.*

Hence, alſo, an inhabitant at the north pole has the ſun above his horizon, and therefore *perpetual day* all the time the ſun is on the north ſide of the equator, that is, for ſix months together. But the ſun is below his horizon, and it is *night* with him all the time the ſun is on the ſouth ſide of the equator, which is alſo for ſix months: or, in other words, the ſun will be ſeen for half a year, and then it will be day; and it will be hidden for half a year, and then it will be night.

An oblique ſphere. We are ſituated in an oblique ſphere. This poſition agrees with the inhabitants who live neither under the poles, nor under the equator; here the equator, and all the circles parallel to it, make oblique angles with the horizon.

It is evident, that in this ſituation, all the parallels to the equator are divided by the horizon into two unequal parts, but the equator into two equal parts; conſequently the day and night are never equal to an inhabitant in an oblique ſphere, but when the ſun is in the equator, that is, twice a year, on the 20th of March, and the 22d of September. All the reſt of the year the days are either longer or ſhorter than the nights; and the ſun, which always appears to move in the ecliptic, deſcribes one of the parallels to the equator, which are all cut by the horizon into two unequal parts. On the northern ſide of the equator, the days are longer than the nights, as long as the ſun is on the north ſide of the equator; but the nights are longer than the days, when the ſun is to the ſouth of the equator.

The portion of the parallels above the horizon is greater in proportion as they are nearer the elevated pole; but when the diſtance of the parallel from the pole becomes leſs than the elevation of the pole, then that parallel, and all thoſe which are included within it, are wholly above the horizon, no part of them ever ſetting or paſſing under it. The contrary happens in the parallels that are ſituated towards the depreſſed pole, a ſmaller portion of theſe being above the horizon, and the greater part lying under it. Thoſe parallels which are nearer the depreſſed pole, than the elevation of the pole, or latitude of the place, remain perpetually (together with the ſtars included within them) under the horizon, and are never viſible to us.

The arch of the equator intercepted between the beginning of Aries, and a ſtar, &c. when on the meridian, is called it's *right aſcenſion.* It is ſo called, becauſe in a *right ſphere* that point of the equator which riſes with a ſtar, &c. comes alſo to the meridian with it. Hence you find the right aſcenſion of a ſtar, &c. by bringing it to the meridian; for that point of the equator which comes to the meridian with it, is it's right aſcenſion. The right aſcenſion of a fixed ſtar is always the ſame, but that of a planet varies.

The arch of the equator intercepted between the beginning of Aries and the point of the equator, riſing or ſetting along with any heavenly body, is called the *oblique aſcenſion or deſcenſion.*

The difference between the right and oblique deſcenſion is called the *aſcenſional difference.* Many problems ſolved by the globes may be performed with the ſphere; it is unneceſſary to ſpeak of theſe here, as I have only introduced the ſphere to give you clear and ſatisfactory ideas of the circles uſed by aſtronomers.

In the middle of this ſphere I have placed a ſmall globe of the earth, ſupported by an axis, the ends of which go through the ſphere in the places of the celeſtial poles. It is ſo contrived, that you may either turn the globe round within the ſphere, or turn the ſphere round the globe; thus this inſtrument will exhibit the real motion of the earth round it's axis within the ſphere of the heaven, or the apparent motion of the heaven round the earth. It will, therefore, ſhew you the correſpondence between the terreſtrial and celeſtial ſpheres, and that the appearances of the heavenly bodies would be the ſame to us, whether they moved round the earth as they appear to do, and the earth ſtood ſtill; or they ſtand ſtill, and the earth is carried round the contrary way.

THE APPEARANCES OF THE STARRY HEAVENS ILLUSTRATED BY AN ARMILLARY SPHERE.

By the ſphere you will readily perceive the truth of the poſitions ſtated, when I was treating of the apparent motion of the ſtarry heavens.

You here ſee that the poles of the earth, when extended, reach the poles of the heavens. By placing a ſmall patch on the different circles of the ſphere to repreſent ſtars, you perceive, that thoſe which are furtheſt from the poles will deſcribe the greateſt circles; and thoſe will deſcribe the largeſt poſſible circles that are ſituated in the equator, which is equi-diſtant from both poles. You here perceive, that a ſtar has acquired it's greateſt elevation when it comes to the upper ſemicircle of the meridian, and it's greateſt depreſſion when it is at the lower circle of the meridian; and that the arch of it's apparition is biſected at the meridian.

The ſphere alſo ſhews you plainly, that if the *circle of revolution* be between the equator and the pole, which is above the horizon, the greateſt portion thereof will be viſible; but if it be on the other ſide the equator, the ſmalleſt portion will be viſible. One half of the equator is always viſible, ſome circles of revolution are wholly above the horizon, and ſome wholly below it; a ſtar in one of the firſt is always ſeen, and one in the laſt is never ſeen. A phenomenon, whoſe circle of diurnal revolution is on the ſame ſide of the equator with the elevated pole, is longer viſible than it is inviſible; the contrary obtains if it be on the other ſide of the equator.

OF THE FIXED STARS, CELESTIAL SIGNS, AND CONSTELLATIONS.

No part of the univerſe gives ſuch enlarged ideas of the ſtructure and magnificence of the heavens, as a conſideration of the number, magnitude, and diſtance of the fixed ſtars. We admire, indeed with propriety, the vaſt bulk of our own globe; but when we conſider how much it is ſurpaſſed by moſt of the heavenly bodies, what a point it degenerates into, and how little more even the vaſt orbit in which it revolves would appear when ſeen from ſome of theſe ſtars; we conceive more juſt ideas of the extent of the univerſe, and of the boundaries of the creation.

Among the many diſtinctions that characterize the fixed ſtars from other luminaries of heaven, that which is afforded by their light, or peculiar luſtre, is the moſt obvious.

The light of the planets is ſteady, becauſe it is reflected; that of the ſtars is bright and lively, and accompanied with a kind of vibration of light, which we call twinkling. This is ſuppoſed to ariſe from the nature of their light as intrinſic, and not received and reflected, and principally from the ſmallneſs of their apparent diameter. Our atmoſphere is full of innumerable little particles, which are continually floating in it; many of theſe are large enough, on coming between the eye and ſuch a point as a fixed ſtar, to hide that point, or take that ſtar out of our view, by intercepting it's rays. But theſe atoms are in perpetual motion, ſo that the ſtar is no ſooner hid by one of them, than it appears again, becauſe the atom has changed it's place; then another comes and again intercepts the view: the ſwift ſucceſſion of theſe moving particles, greatly aſſiſts in cauſing that appearance which we term twinkling. Or it may probably ariſe from ſomething in the eye itſelf, for we are continually ſhifting and cloſing them, even when we are not conſcious of doing it, and a ſtar being but a point, the ſmalleſt motion of the eye is ſufficient to make us loſe it; perhaps the impreſſions are ſo weak, as not to be able to keep the viſive faculty awake, except as it were, by fits.

As the ſtars do not change their relative ſituations one to the other, and as they are uſed to compare the relations and motions of the planets, it became neceſſary to find out ſome method of diſtinguiſhing the ſtars from each other; and as they do not change their relative poſitions, aſtronomers endeavoured to make an exact deſcription of them, and by repeated obſervations determined the poſition and order which ſubſiſts among them.

To avoid confuſion in deſcription, and be able to point out any particular ſtar, without being obliged to give a name to each, they are divided into ſeveral parcels; to each of theſe parcels is aſſigned a figure at pleaſure; theſe aſſemblages, or groupes of ſtars, are called CONSTELLATIONS. Thus a number of ſtars near the north pole is called the *bear*, becauſe the ſtars which compoſe it are at ſuch diſtances from each other, that they may fall within the figure of a bear. Another conſtellation is called the *ſhip*, becauſe that collection of ſtars which compoſe it, is repreſented upon a celeſtial globe as comprized within ſome part of the figure of a ſhip.

The diviſion of the ſtars into conſtellations is of the higheſt antiquity; there are no books ſo ancient, in which the heavens are at all conſidered; but we find them treated of as diſtinguiſhed into conſtellations; Heſiod and Homer mention ſeveral by names that are now known, and we find Job ſpeaking of Orion and the Pleiades. *It was not from ignorance* that the moſt ancient people aſſigned the names of men and beaſts; they had in many things, reaſons which are not common to us, and it was ſo in this; and thoſe who attend *to the uſe and application of the images drawn from natural objects in the ſcriptures,** will not find it difficult to decypher the hieroglyphic language of the heavens, and they will alſo find it a pleaſing ſource of rational entertainment.

As the fixed ſtars appear of different degrees of magnitude and ſplendor, they are divided into ſix different claſſes. Thoſe which ſeem the largeſt and brighteſt, are called ſtars of the *firſt magnitude*; the ſmalleſt that we can ſee with the naked eye, are called ſtars of the ſixth magnitude: and the intermediate ones, according to their different apparent ſizes, are called of the ſecond, third, fourth, or fifth magnitudes. Thoſe ſtars which cannot be ſeen without the aſſiſtance of a teleſcope, are not reckoned in any of theſe claſſes, and are called TELESCOPIC STARS.

By a knowledge of the fixed ſtars and their poſitions, we obtain ſo many fixed points, by which we may obſerve the motions of the planets; and the relation of theſe motions to each other, which become

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* The application of the images drawn from natural objects to ſpiritual ſubjects in the ſcriptures, gives a full, clear, ſatisfactory, and univerſal key to all the heathen mythology; it includes and explains the partial, agricultural, and aſtronomical views of this ſubject; fills up their deficiencies; ſhews their true value, and leaves French aſtronomers, and their atheiſtical views, to the deſerved contempt that their affectation of wiſdom and their real ignorance deſerves.

become ſo many land marks (if the word may be allowed) to aſcertain the ſituations of other celeſtial bodies, and the varieties to which they are ſubject. For from the ſame place, the motions of the heavenly bodies can only be eſtimated by the angle formed at the ſpectator's eye, by the ſpace which the moving body paſſes over.

To meaſure theſe ſpaces, the ſtars muſt be uſed, and they are conſidered as ſo many luminous points fixed in the concavity of a ſphere, whoſe radius is indefinite, and of which the obſerver's eye is the center. We learn from hence the neceſſity of forming an exact *catalogue* of the ſtars, and of determining their poſitions with accuracy and care. With ſuch a *catalogue*, the ſcience of aſtronomy begins.

Although to thoſe who are unacquainted with the nature of celeſtial obſervation, it might at firſt ſight appear almoſt impoſſible to number the ſtars; yet their relative ſituations have been ſo carefully obſerved by aſtronomers, that they have not only been numbered, but even their places in the heavens have been aſcertained with greater accuracy, than the relative ſituation of moſt places on the ſurface of the earth.

The greateſt number of ſtars that are viſible to the naked eye, are to be ſeen on a winter's night, when the air is clear, and no moon appears. But even then a good eye can ſcarce diſtinguiſh more than one thouſand at a time in the viſible hemiſphere: for though on ſuch a night they appear to be almoſt innumerable, this appearance is a deception, that ariſes from our viewing them in a tranſient and confuſed manner; whereas, if you view them diſtinctly, and only conſider a ſmall portion of the heavens at a time, and after ſome attention to the ſituation of the remarkable ſtars contained in that portion, begin to count, you will be ſurprized at the ſmallneſs of their number, and the eaſe with which they may be enumerated.

Hipparchus, the Rhodian, about an hundred and twenty years before the birth of Chriſt, was the firſt among the Greeks who reduced the ſtars into a catalogue; daring, according to Pliny, "to undertake a thing, which ſeemed to ſurpaſs the power of a divinity; that is, to number the ſtars for poſterity, and to reduce them into order; having contrived inſtruments, by which he marked the place and magnitude of each ſtar. So that by theſe means we can eaſily diſcover, not only whether any of the ſtars periſh, and others grow up, but alſo whether they move, and if ſo, the direction of their motion, whether they increaſe or diminiſh; thus putting poſterity in poſſeſſion, as it were, of the heavens." His catalogue, firſt adopted by Ptolemy, contained only 1026 ſtars. Since that time the liſt has been conſiderably augmented, and is daily receiving freſh increaſe, by the improvement of teleſcopes.

Several aſtronomers have followed Hipparchus in the ſame arduous undertaking. In 1603, *J. Bayer* publiſhed celeſtial charts of all the known conſtellations, and of the viſible ſtars of which they are compoſed. In theſe charts every ſtar is diſtinguiſhed by a letter. The largeſt ſtar in the conſtellation is marked with the firſt letter of the Greek alphabet; the next in apparent ſize is marked with the ſecond letter, and ſo on. If there are more ſtars in the conſtellation than there are letters in the Greek alphabet, he marks the remainder with the letters of the Roman alphabet. When a ſtar is mentioned with the letters of the Greek or Roman alphabet, it is always with the additional name of the conſtellation to which it belongs; and thus to thoſe who are acquainted with the figures of the conſtellations, and with the catalogue of fixed ſtars, it becomes as determinate a denomination, as if the ſtar was called by a proper name, and the ſame purpoſe is anſwered in a more familiar manner, and with leſs burthen upon the memory. Among the various catalogues, the moſt copious, and as generally eſteemed the beſt, is that called Hiſtoria Cœleſtis, of our countryman, Flamſteed.*

The number of the ancient conſtellations was 48; in theſe were included 1022 ſtars. Many conſtellations have been added by modern aſtronomers; ſo that the catalogues of Flamſteed and De la Caille, when added together, are found to contain near five thouſand ſtars. The names of the conſtellations, their ſituation in the heavens, with other particulars, are beſt learned by ſtudying the artificial repreſentation of the heavens, a *celeſtial globe*.

The galaxy or *milky way* muſt not be neglected; it is one of the moſt remarkable appearances in the heavens; it is a broad circle of a whitiſh hue, in ſome places it is double, but for the moſt part conſiſts of a ſingle path ſurrounding the whole celeſtial concave. The great Galileo diſcovered by the teleſcope, that the portion of the heavens which this circle paſſes through, was every where filled with an infinite multitude of exceeding ſmall ſtars, too ſmall to be diſcovered by the naked eye; but by the combination of their light diffuſing a ſhining whiteneſs through the heavens. Mr. Brydone ſays, that when he was at the top of Mount Etna, the milky way had the moſt beautiful effect, appearing like a pure flame that ſhot acroſs the heavens.

This idea of the milky way, that it is formed of ſay, how far the univerſe extends, or where are the limits of it? where the Creator ſtayed "his rapid wheels," or where he "fixed the golden compaſſes?"

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* A new one has lately been publiſhed by the Rev. Mr. Woolaſton.

TO OBTAIN A KNOWLEDGE OF THE CONSTELLATIONS.

Let us ſuppoſe ourſelves, in a froſty and bright evening of the month of *January*, ſeated about nine or ten o'clock, on a commanding eminence, beneath an open ſky; when every planet walks forward in ſteady ſtatelineſs, when the hoſt of ſtars crowd the heavens with glory.

The firſt view of the heavens creates a confuſion of pleaſure and aſtoniſhment. The general irradiation elevates, but the ſeemingly irregular aſſemblage confounds the mind. Willing to form an intimacy with each portion of theſe glorious maſſes, fix on ſome of the moſt diſtinguiſhable groups, and make uſe of thoſe as marks, to conduct you through the reſt. To every clump of ſtars, if we may uſe the expreſſion, we will affix the name that antiquity firſt gave it.

The collection we proceed from is that large irregular ſquare, within which you may obſerve three bright ſtars, placed very near each other, on a ſtrait oblique line; beneath which are three others, of inferior luſtre, hanging from them in a manner. This the ancients called *Orion.* The two higheſt ſtars in this ſquare form his arms; the two loweſt, his legs; the three bright ſtars in the middle are his belt; and the three ſmaller, which hang from them, are underſtood to deſign the garment that covers his thighs, or more properly his faulchion.

Theſe three bright ſtars, ſometimes called *Orion's Belt*, ſometimes the Three Kings, by their direction point out to us, on one ſide, *Sirius*, or the Dog Star; on the other, the *Pleiades*. Sirius is that remarkable ſtar, diſtinguiſhable from any other by it's ſcintillation and luſtre. You will ſee it on the ſouth-eaſt ſide of Orion.

The Pleiades, or the Seven Stars, lie on the north-weſt of Orion: they are very eaſily known, by being ſo cloſely maſſed together. Beſides, they are almoſt in a direct line from Sirius, through Orion's Belt; they are on the back of another conſtellation, called the *Bull*.

That very large ſtar, on a right line, half way betwixt the Pleiades and the ſtar that forms the weſtern ſhoulder of Orion, is called the *Bull's Eye*, or Aldebaran.

That large ſtar, which, you may perceive, rms a triangle of equal ſides with Sirius and ion's Belt, is called *Procyon*, or the *Leſſer Dog*. It lies to the north of Sirius, and to the eaſt of Orion.

Imagine a ſtrait line, extending towards the north, from Procyon or the Leſſer Dog; and the firſt bright ſtar it meets with is *Caſtor*, or one of the conſtellations called *Twins:* very near which is another bright ſtar, called *Pollux*, the ſecond of the Twins. This laſt lies ſouth-eaſt with regard to Caſtor.

Thoſe four ſtars that lie in a right line, at equal diſtances, and about half way betwixt the eaſt ſhoulder of Orion and the Twins, are the four feet of the Twins.

A line drawn from the bright ſtar that forms the weſt foot of Orion, through the ſtar that forms his weſtern ſhoulder, carries you on to the next ſtar, called the *ſouthern horn of the Bull*. This ſtar, and the weſt foot of Orion, are equally diſtant from his weſt ſhoulder.

The *northern horn of the Bull* is brighter than the ſouthern; it lies on a ſtrait line with the eaſt ſhoulder of Orion, and the ſouthern horn of the Bull.

The Ecliptic, or the annual path which the ſun ſeems to make in the heavens, paſſes betwixt the two horns of the Bull.

A line prolonged from the weſt foot of Orion, through Procyon, or the Leſſer Dog, brings you to that very bright ſtar called *Regulus*, or the Lion's Heart, which lies eaſt by north-eaſt from Procyon, and at ſome diſtance from it.

If you fancy a line drawn from the ſtar in the middle of the Twins, through Regulus, it will there paſs beneath a ſquare of bright ſtars near Regulus, which form the conſtellation called the Lion. The firſt bright ſtar, lying eaſt by north-eaſt from Regulus, and almoſt as large as itſelf, is called the *Lion's Tail.*

Extend, in imagination, a line from a bright ſtar, that lies half way betwixt the feet of the Twins and their heads, towards a bright ſtar that lies eaſt, and it will paſs through the *Crab* (which lies exactly half way betwixt the Twins and the Lion) remarkable by one bright ſtar, and a cloudy clump of ſmall ſtars adjoining to it. This conſtellation, you may obſerve, is hard to be remarked.

If you ſuppoſe a line drawn through the Twins, north-weſt by north, it will touch a bright ſtar in the helmet of the conſtellation called *Auriga*, which is at a conſiderable diſtance.

A very conſpicuous ſtar lies ſouth-weſt by ſouth from this one. This beautiful ſtar is called the *Goat;* and, due eaſt, oppoſite to it, lies another, which, with three or four more near them, ſituate to the ſouth, forms the whole conſtellation of Auriga.

A line drawn from Procyon, by Aldebaran, weſtward, leads you to the conſtellation called the *Ram*. This is reckoned the firſt conſtellation in the heavenly order, ſince the maſs of ſtars that form it's head, lie neareſt that point where the ſun equally divides the year, making the nights equal to the days. The firſt ſtar in the Ram's Horn, which is the ſtar aſtronomers reckon from, lies thirty-ſix degrees more to the weſt than Aldebaran.

Draw a line, in fancy, from the Seven Stars, or the Pleiades, north-north-weſt, and the firſt very bright ſtar it meets is the firſt ſtar in, or the *Breaſt of Perſeus*; the ſtar to the north-weſt of this is his right ſhoulder: the ſtar to the weſt is the left: and the very brilliant ſtar, ſouth by ſouth-weſt of the Breaſt of Perſeus, is the firſt ſtar in the conſtellation called *Meduſa's Head*; next to which, there are three others, very near, that form the whole head, ſomething in the form of a ſquare.

The very bright and beautiful ſtar, lying eaſt by north-eaſt from the Lion's Tail, is *Arcturus*, the largeſt in the conſtellation called *Boötes*, ſituate between his legs.

The maſs of ſtars weſt by north-weſt of *Arcturus*, between it and the Lion's Tail, is called *Berenice's Lock*.

A line drawn from Arcturus, north by north-weſt, falls in with the laſt ſtar of the tail of the capital conſtellation called the *Great Bear*. This laſt is formed by ſeven ſtars, in the form of a plough: it is the moſt conſpicuous conſtellation in the heavens, and therefore may ſerve to point out others. Of this conſtellation, the four ſtars that lie towards the north form an irregular ſquare: of which the two ſtars, that are the moſt northern, point northwards, to a bright ſtar, not very diſtant, which is called the *polar ſtar*, as it lies only two degrees, or thereabouts, from the pole of the world.

The *Swan* is a very remarkable conſtellation, in the form of a great croſs. A line drawn from the Twins, through the polar ſtar, meets the Swan on the other ſide, at much about the ſame diſtance.

A line drawn from the northern ſide of the ſquare of the Great Bear, through the pole, paſſes through the middle of the conſtellation of *Pegaſus*. This too is a ſquare, formed by four bright ſtars, the moſt northern of which forms the head of *Andromeda*. A line carried, in fancy, from the Pleiades to the Ram, falls upon *Algenib*, the beautiful ſtar in the wing of Pegaſus. The moſt northern of the ſouthern ſtars of Pegaſus, are called *Scheat*, and *Markab*: Scheat lies to the north, and Markab to the ſouth.

Caſſiopeia is a conſtellation directly oppoſite to the Great Bear, through the polar ſtar, in ſuch a manner, that the line that paſſes through the middle of the Great Bear, by the polar ſtar, paſſes alſo through Caſſiopeia on the other ſide of the pole. This conſtellation is formed of ſix or ſeven ſtars, in the ſhape of a chair turned upſide down.

Cepheus is that conſtellation you ſee contained betwixt the polar ſtar, Caſſiopeia, and the Swan. A line drawn from the polar ſtar to the Swan's Tail, paſſes through the two firſt great ſtars in the conſtellation of Cepheus.

The *Leſſer Bear* has almoſt the ſame ſhape as the Greater, and is parallel to it, but the ſituation is inverted. The polar ſtar is the laſt in it's tail. The two largeſt ſtars in this conſtellation are on a line drawn through the center of the ſquare of the Great Bear, perpendicular to both it's greater ſides.

The *Dragon's Tail* lies betwixt the polar ſtar and the ſquare of the Great Bear. The four ſtars in it's head lie ſouth by ſouth-eaſt with regard to the Leſſer Bear, and almoſt form an exact ſquare.

Such are the conſtellations that moſt conſpicuouſly adorn the face of heaven, in a winter night. Thoſe which ſhew themſelves during the nights of ſummer, are not ſo eaſily noted; but by the help of what I have pointed out to you, I think I ſhall be able to render them diſtinguiſhable.

When the ſtar in the middle of the tail of the Great Bear, is in the meridian above the polar ſtar, and in the higheſt point of heaven, which happens about nine o'clock of one of the laſt evenings in May, you will then obſerve, towards the ſouth, in the meridian, that very beautiful ſtar called the *Virgin's Spike*. You ſee this ſtar forms a triangle, of equal ſides, with Arcturus and the Lion's Tail.

A little more to the right, but lower than the Virgin's Spike, you may remark a kind of ſquare, formed by four principal ſtars: this conſtellation is called the *Crow*.

A line drawn from the two moſt eaſtern ſtars of the ſquare of the Great Bear, through the Lion's Heart, Regulus, meets, towards the ſouth, the Heart of *Hydra*. It's head is to the ſouth of the *Crab*, betwixt Procyon and Regulus. This conſtellation of Hydra extends from the Leſſer Dog to the lower part of the Virgin's Spike.

Betwixt Hydra and the Crow, but to the weſt of this laſt, is ſituated the *Crater*, or the Cup. The kind of ſmall ſquare formed by it is remarkable enough, ſo that you will not be at a loſs to fix upon it.

A line drawn eaſt-north-eaſt from the brighteſt ſtar in the Swan, reaches the bright ſtar in the *Lyre*, which is one of the moſt ſplendid in the heavens. It almoſt makes a right-angled triangle with Arcturus and the polar ſtar.

The *Crown* is that ſmall conſtellation, ſituate betwixt Arcturus and the Lyre: it ſometimes ſhews itſelf in the form of an oval, with eight pretty viſible ſtars: ſometimes only as three bright ſtars lying very cloſe to each other, bearing weſt by ſouth-weſt from the Lyre. A line carried from the two firſt ſtars in the tail of the Great Bear, points out the Crown, generally called Corona Borealis, or the Northern Crown.

That very reſplendent ſtar, which you ſee to the ſouth of the Lyre and the Swan, is called the *Eagle*. It is very perceivable, by being placed in a ſtrait line betwixt two other bright ſtars that lie very near it.

The clump of ſtars that lie to the ſouth of, and next to the Eagle, is called *Antinous*.

The line, or the arch of a great circle, which paſſes through Regulus and the Virgin's Spike, leads you on, eaſt-ſouth-eaſt, to a very bright ſtar called *Antarés*, or the firſt of the *Scorpion*. This conſtellation is very remarkable; for to the ſouth of this very bright ſtar there is an arch of ſtars, with the concave towards the north, and the convex to the ſouth, which forms the tail or ſting of the Scorpion. Antarés ſeems likewiſe to be a center to a circle of bright ſtars round it.

That bright ſtar that lies half way betwixt the Virgin's Spike and Antarés, is the ſouthern ſcale of the conſtellation called the *Ballance*. The next bright ſtar to this, north-eaſt by north, is the northern ſcale of the ſame conſtellation.

That other conſtellation which follows the Scorpion, that is, ſomewhat more to the eaſt, is called Sagittarius. The Virgin's Spike and Antarés point to it, eaſt-ſouth-eaſt. It lies upon a line drawn from the middle of the Swan through the middle of the Eagle.

An arch drawn from Antarés to the polar

ſtar, firſt paſſes through the conſtellation called Ophiucus, or *Serpentarius*, and a little higher meets the conſtellation *Hercules*. A line from Antarés to the Lyre, paſſes betwixt the heads of Hercules and Ophiucus, which lie very near to one another. The moſt eaſtern and ſouthern of the two is the head of Ophiucus. The ſtars that lie immediately to the north of the head of Hercules, form the conſtellation of Hercules; and thoſe that you ſee to the ſouth of the head of Ophiucus, conſtitute the conſtellation of that name, together with a part of the Serpent, which lies eaſt and weſt of Ophiucus.

A line drawn through the Lyre and the Eagle, towards the ſouth-eaſt, leads you to thoſe two ſtars, near each other, which form the head of the conſtellation called *Capricorn*. Thoſe two other ſtars, much about the ſame diſtance, lying beneath the *Water-bearer* towards the ſouth, form the tail of Capricorn.

A line extended from the Eagle through Capricorn's tail, almoſt ſouth-eaſt, leads you to that effulgent ſtar called Fomalhaut, or the *Southern Fiſh*.

The ſmall group of ſtars in the form of a bright croſs, you ſee next to the Eagle, lying north-eaſt by eaſt, is called the *Dolphin*.

Draw a line from the Lyre upon the Dolphin, prolong it to the ſouth, at the ſame diſtance from the Dolphin as the Dolphin is from the Eagle, and the conſtellation called Aquarius, or Water-bearer, will be ſituated a little to the eaſt of that line. In deſcending from the Dolphin to Fomalhaut, you paſs through the whole length of *Aquarius*, beginning by the two bright ſtars that form his ſhoulders.

Protract a line from the Goat through the Pleiades, and it will lead you to a bright ſtar that is the firſt in the head of the conſtellation called the *Whale*. A line drawn from Aldebaran through this laſt, carries you through the body of the Whale down to the bright ſtar that forms it's tail, after paſſing near thoſe three remarkable ones that form it's back.

Thoſe two groups of ſtars that lie immediately ſouth-eaſt and north-eaſt of the great ſtar in the wing of Pegaſus, are called the *Fiſhes*. The firſt bright ſtar that lies ſouth-eaſt of theſe is termed the Fiſhes Knot, ſuppoſed to join them together. This laſt is the largeſt of this conſtellation, and is the firſt bright ſtar ſituate to the ſouth of the Ram's head.*

This general outline of the places of the conſtellations, may in time form an habitude of referring to any particular ſpot of the heavens. But the ſpace is too wide for one graſp. I have only ſhewn you the expanſive field you have to work in.

When you behold the ſky, the ſplendor of the ſtars, and that grand luminary which diſcovers all things that ſurround you, aſk yourſelf from whence come all theſe things? Who has conſtructed this immenſe canopy of the heavens? Who has placed in this firmament thoſe innumerable lights? Who has appointed thoſe ſtars to move in ſuch order, and that ſun to enlighten and fertilize the earth? And your heart will anſwer, It was the *power* and *wiſdom* of GOD that called all theſe things into being. What other than an intelligent and omnipotent power could have formed that grand and magnificent arch above us? Who could have given thoſe globes that perpetual motion? Whence comes that connection, that harmony, that beauty diſplayed in all their parts? Who has appointed all theſe things with ſo much exactneſs in number, weight, and meaſure? Who has preſcribed to theſe immenſe

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* Cometilla, or Views of Nature, p. 69 to 88. De la Lande's Aſtronomie, vol. 1.

immenſe bodies thoſe laws diſcoverable only to men of the greateſt abilities, and moſt profound wiſdom.

All theſe queſtions refer to thee, MOST ADORABLE CREATOR, ſelf-exiſtent, independent, infinite being; to THEE all the heavenly bodies owe their exiſtence, their laws, their arrangements, their power, and all the advantages they are of to this world. LOVE prompted thy INFINITE WISDOM to contrive, and employed thy OMNIPOTENCE to execute the glorious univerſal plan; love ſtill inclines the Almighty Maker to preſerve his ſtupendous work, to uphold the perfect order running through the whole, to bleſs the creatures he has made, and under it's unceaſing influence will he proceed throughout all the boundleſs ages of eternity.*

DIVINE LOVE, thou filleſt heaven and earth, pervadeſt the mighty whole of nature, and formeſt the ſinews that knit together all the parts and members in amicable concord. The *earth*, that holds down heavy bodies on her ſurface, is but a maſs of matter diviſible beyond the reach of human comprehenſion; the *ſun* whoſe potent graſp compreſſes the wide wandering orbs around him, is but an aſſemblage of innumerable atoms. It is the united force of imperceptible particles that together form that gravitation which fixes the everlaſting mountains, binds down the reſtleſs ocean within his capacious bed, entangles the unconnected air that it diſſipate not itſelf, keeps the moon conſtant in her monthly courſes, curbs in the huge planetary worlds and roving comets, that they tranſgreſs not the due bounds in their wild excurſion. Yet matter joins in thoſe great works by blind neceſſity; a general mechaniſm runs through the component parts, and compels them to act in concert as one agent; but this mechaniſm muſt be adminiſtered, and the force whereby it prevails, begun and continued by ſpiritual ſubſtance; for body can only tranſmit the motion it has received, and is but the *channel*, not the origin, of the impulſe it conveys.

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* Tucker's Light of Nature, vol. iv, part 2. p. 341.

By THEE, all-chearing, all-ſuſtaining love, we may approach the neareſt to our elder brethren, enthroned above in realms of bliſs and glory;—by thee beſt attain ſome faint reſemblance of our Maker, for GOD is LOVE, and without it the mightieſt of his creatures are nothing. When it's well woven bands unite ſocieties, they act with greater vigour, and to better purpoſe, than private intereſt, fear, and cobweb law can make them; and wert thou to prevail throughout mankind, thou wouldſt baniſh war and injury, waſte and idleneſs, vanity and competition, and reſtore a paradiſe upon earth.

END OF VOL. III.